Ministry of Forests, 518 Lake Street, Nelson, British Columbia V1L 4C6

Armillaria Studies in British Columbia 1975 - 1995: Summary

Prepared for the Armillaria Research Working Group,
Nelson Forest Region, by:

G. Davis
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and
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Technical Report TR - 017

forest sciences
NELSON FOREST REGION

Ecology • Geomorphology • Hydrology • Pedology • Silviculture • Silvicultural Systems

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Abstract

This report provides summaries of the majority of past and ongoing Armillaria studies conducted in British Columbia from the mid 1970s to 1995. Pertinent results of each study are summarized, and limitations in documentation are discussed. The format of the summaries emphasizes study design, methodology, and site characteristics, because these factors influence not only site-specific interpretations but also inter-project extrapolation.

Topic areas range from control treatment options to the ecological role of Armillaria in natural forests. Many of the short-term studies provide exciting insight into the complexity of pathogen-host-environment interactions. The more long-term studies will provide much needed information on 5-year and +10-year response to management options. Other projects provide important background information for future planning of operational risk-management trials. Together, the 44 projects provide a solid foundation for developing future complementary and integrated research on Armillaria.

Acknowledgements

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This project could not have been completed without the support and participation of the professionals throughout BC who have worked on the topic of Armillaria root disease. Their time and perseverance through the seemingly endless questions are gratefully acknowledged. The compilers would also like to thank Jeff Beal, George Krumlick, Duncan Morrison, John Muir, John Pollack and Stefan Zeglen for their constructive comments on the final draft. A special thank you is extended to Mike Stone, Economics and Trade Branch, BCMOF for preparing Summary 18. Lastly, the time and thoughts of Jenny Marsden and Kathi Hagan on the final edit are very much appreciated.

1.0 Introduction

Research on Armillaria root disease in BC was initiated in the mid to late 1970s by the Canadian Forest Service. Since 1985 the number of research initiatives has risen significantly due to an increased awareness of the losses in timber production and associated economic impacts of this disease, and the potential for forest management activities to aggravate endemic disease levels (Kile et al. 1991).

Armillaria species are natural components of many forest ecosystems (McDonald et al. 1987a; Kile et al. 1991). Armillaria are facultative parasites with both saprophytic and parasitic phases. As mortality agents, they have strong influences on forest structure and productivity (Filip and Schowalter 1993). They contribute to the ecological diversity of forests by playing roles in:

1. nutrient cycling through tree mortality (Schowalter and Filip 1993; Kile et al. 1991);

2. creating wildlife habitat and enhancing diversity of vegetation species through the development of canopy openings (e.g. via tree deformation and mortality); and

3. selective tailoring of tree density and species composition to site-specific conditions (Goheen and Hansen 1993; Schowalter and Filip 1993; Kile et al. 1991).

Six species of Armillaria have been identified in BC (Morrison et al. 1985). Only *Armillaria ostoyae* and *Armillaria sinapina* are geographically widespread in the province, and concerns for forest managers. *Armillaria sinapina* is found mainly on hardwoods and is weakly pathogenic. In some ecosystems, *Armillaria sinapina* may compete with *Armillaria ostoyae* for substrate. *Armillaria ostoyae* is highly pathogenic, causing primary disease on both conifers and hardwoods, although conifers are the principal host.

The damage caused by *Armillaria ostoyae* is most severe in Interior forests where *Armillaria ostoyae* is capable of killing trees throughout a rotation. In Coastal areas, *Armillaria ostoyae* causes mortality mainly in plantations and in young stands (Morrison et al. 1985, 1991). Factors responsible for observed differences in damage levels between Coastal and Interior sites in BC (Morrison et al. 1985; Cruickshank 1996) have not been clearly established.

Hypotheses include:

- Differences in the presence and/or the abundance of *Armillaria ostoyae* under different soil moisture regimes. E.g. absent or low frequency in wet and very dry soil conditions due to anoxia in the former and reduced rhizomorph growth in the latter (Cruickshank 1996).

- Differences in host susceptibility (Morrison et al. 1991).

- Differences in juvenile tree growth rates such that in Coastal ecosystems the tree roots grow away from the fungus (Cruickshank 1996).

Current knowledge suggests that in natural, mature, undisturbed forests *Armillaria ostoyae* and its hosts are in a state of dynamic equilibrium within the local abiotic stress factors (e.g. climate, environment, fire) and biotic stress factors[1](e.g. genetic, insect, disease) (Morrison et al. 1991; Kile et al. 1991). Recent studies in a small number of undisturbed forests have shown that the incidence of trees with asymptomatic, below-ground infection is 4 or 5 times the incidence of trees with detectable above-ground symptoms; below-ground incidence ranged from about 10% in dry zones to about 80% in moist zones (Summaries 1 and 21). Because the host and pathogen are in dynamic equilibrium, the incidence of disease in these forests does not threaten the long-term productivity of the forest, as do broad-scale lethal epidemics (Goheen and Hansen 1993).

In managed stands, historic and current human activities represent added stress factors. Human activities have contributed—directly through such events as fire suppression or selection harvest, or indirectly through such events as introduction of white pine blister rust—to broad-scale site disturbances and shifts in ecosystem processes (e.g. forest succession) and components (e.g. species composition) (Hagle et al. 1992). The documented increase in *Armillaria ostoyae* severity associated with forest management practices has been attributed to the disruption in the natural host-pathogen-environment equilibrium (Hagle et al. 1992; Kile et al. 1991; Morrison et al. 1991).

Factors contributing to this disruption include increased food sources for root disease fungi and shifts in species composition towards more susceptible tree species. From a timber management perspective, the resulting economic losses can be significant. In addition to timber losses and the creation of unproductive areas through chronic infections, other effects include changes in tree species composition, creation of hazard trees, and restricted choice of silviculture systems (Kile et al. 1991).

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[1] Trees are continually subjected to stress factors, e.g. during seasonal and ontogenetic growth and development. However, the effects of stress agents on physiological processes, such as defense mechanisms, depend on the timing, intensity, and duration of the stress. Healthy trees are better able to maintain normal physiological processes (Filip and Schowalter 1993).

Based on the existing research in BC, the incidence of infection and mortality resulting from *Armillaria ostoyae* is influenced by various factors including:

- tree species (stand composition), size, and age;
- biotic stress factors, e.g. insects, that affect tree growth and vigour;
- forest management practices, including harvesting and silviculture treatments; and
- regional climate and/or site environmental factors, i.e. reflected in the biogeoclimatic classification.

The challenge of future research is to better quantify the variation in host resistance and disease expression, and their interaction in managed and unmanaged stands within the context of regional and local environmental factors. A detailed understanding of the host-disease-environment interaction is the framework needed to develop risk-management tools. These tools will help identify forest management options that will avoid disrupting the natural host-pathogen equilibrium, and help restore it where necessary.

1.1 Objectives

The multi-disciplinary provincial-level Armillaria Research Working Group (ARWG) was established in 1992 to address the complexity of the host–pathogen–environment interaction and the effects of available root disease management options on timber and other forest resources. The mandate of this group is to co-ordinate and undertake inter-disciplinary research on the topic of Armillaria root disease. One of the first tasks of the ARWG was to establish communication between professionals in BC involved in research on Armillaria root disease. A preliminary review of ongoing projects and priority research topic areas (refer to Appendix A) was initiated in April 1993. This document is a formal presentation of the information gathered up to early 1995.

The objectives of this report are to:

1. Compile summaries of Armillaria-related projects recently completed or underway in BC.
2. Provide a list of professionals in BC working on Armillaria-related topics.
3. Provide an overview of projects categorized by topic areas in order to assist the ARWG in future research prioritization.

2.0 Armillaria Research in BC

2.1 Contacts

Professionals working on Armillaria root disease topics in BC were contacted in 1994 (Table A) and requested to participate by providing documentation or summary information on their existing project(s). Contacts were not necessarily authors.

At the suggestion of J. Muir, Forest Health, Silviculture Branch, BC Ministry of Forests, six studies summarized in the document *Compilation of Forest Health (Pest Management) Projects Funded by British Columbia Ministry of Forests Under the 1985-1990 Forest Resources Development Agreement* were added to the compilation—almost verbatim—because, at the time documentation was being gathered, the BCMOF contacts were unable to participate.

2.2 Compilation

2.2.1 Summary Format

The projects are variable in nature, ranging from short-term operational trials to long-term multi-faceted research studies. The majority of the projects are either in the preliminary data-collection or data-analysis phase. Documentation (e.g. working plans, progress reports) is generally limited; drafting of the summaries therefore relied heavily on discussions with contacts.

Each project is summarized using a standard format (Table B). Site maps are included for long-term projects. Individual projects are presented in Section 4.0, alphabetically by first author. Each project is summarized using a standard format that includes an overview of activities and interim results. Site maps are included for long-term projects. Definitions of selected terms are in Appendix B, and abbreviations that appear in site characteristics tables are explained in Appendix C.

Each summary emphasizes study design, methodology, and site characteristics, because these factors influence not only site-specific interpretation but also inter-project extrapolation. The level of detail does not permit replication of each project, but is sufficient to identify:

- factors that may influence comparisons between studies, i.e. geographical, environmental, experimental, and
- professionals using similar research methodologies and/or measurement techniques.

Table A. Project coordinators, originators, and/or authors.

Name	Title/Affiliation	Summary No.	Contact No.
Allen, Eric	Research Pathologist, Pacific Forestry Centre	1	250/363-0600
Beale, Jeff	Operations Manager, Resource Planning, Dawson Creek Forest District	9	250/784-1205
Chapman, Bill	Research Pedologist, BCMOF, Cariboo Forest Region	2	250/398-4404
Chu, D.	Former technician, Pacific Forestry Centre	24	unavailable
Cruickshank, Mike	Researcher (M.Sc.), Simon Fraser University	3	unavailable
Darbyshire and Sons	Consultant	4	unavailable
Davis, Gerry	Research Forest Ecologist, BCMOF, Vancouver Forest Region	5	604/751-7118
De Long, Debbie	Research Silviculturist, BCMOF, Nelson Forest Region	6, 7	250/354-6707
Doidge, Don	Regional Pathologist, BCMOF, Cariboo Forest Region	8, 43	250/398-4442
Edquist, Kevin	Woodlot Forester, BCMOF, Golden Forest District	9	250/344-7500
Hardy, R.W.	Consultant	26	unavailable
Henderson, Steve	Forester, Integrated Wood Service, Kamloops	43	250/828-7977
Hitchcock, C.	Statistician, Canadian Wildlife Service, Delta	34	604/666-0143
Hope, Graham	Regional Pedologist, BCMOF, Kamloops Forest Region	10	250/828-4127
Hopkins, Kory	Co-op Student, BCMOF, Nelson Forest Region	11	unavailable
Johnson, A.	Formerly technician, Pacific Forestry Centre	24	unavailable
Kimmur Forestry	Consultant, Nelson	12	unavailable
Klaus Roethel	Consultant	13	unavailable
Krumlik, George	Research Scientist, Forest Health, Ministry of Forests Research Branch	14, 15	250/387-3040
Laing, McCullock	Consultant	16	unavailable
Machmer, Marlene	Wildlife Ecologist, Pandion Ecological Research Ltd., Ymir	34	250/357-2246
MacKenzie, Bruce	Co-op Student, BCMOF, Nelson Forest Region	17, 18	unavailable
Merler, Hadrian	Regional Pathologist, BCMOF, Kamloops Forest Region	42	250/828-4176
Morrison, Duncan	Research Scientist, Pathogen Control, Pacific Forestry Centre	14,15, 19-24	250/363-0642
Nevill, Ralph	Consultant, Ecofor Resource Consultants, Victoria	14, 15	250/363-0775
Norris, Don	Regional Pathologist, BCMOF, Nelson Forest Region	4, 9, 12, 13, 16-18, 31, 36	250/354-6142
Pollack, John	Forest Sciences Officer, BCMOF, Nelson Forest Region	7, 25	250/354-6274
Pollard, Adriane	Contact: John Muir, BCMOF	41	250/387-8740
Price, Larry	Landscape Forester, BCMOF, Nelson Forest Region	26	250/354-6239
Quesnel, Harry	Research Ecologist, BCMOF, Nelson Forest Region	7	250/354-6709
Redfern, Lawrence	Soil Scientist, Crestbrook Forest Ltd., Kimberley	27	250/426-8241
Reich, Richard	Regional Pathologist, BCMOF, Prince George Forest Region	9, 28-30	250/565-6743
Robinson, Richard	Researcher (Ph.D.), Pacific Forestry Centre	31	250/266-8054
Safranyik, Les	Research Scientist, Pacific Forestry Centre	15	250/363-0600
Schulting, J.	Consultant	32	unavailable
Senyk, J.	Researcher, Pacific Forestry Centre	40	250/363-0600
Spencer, Paul	Researcher (Post Doc.), Pacific Forestry Centre	33	unavailable
Steeger, Chris	Wildlife Ecologist, Pandion Ecological Research Ltd., Ymir	34	250/357-2246
Stewart, Rick	Forest Health Officer, BCMOF, Nelson Forest Region	11, 17, 18	250/354-6144
Thompson, Chris	Research Silviculturist, BCMOF, Nelson Forest Region	7, 35	250/354-6704
T.M. Tompson…	Consultant	36	unavailable
van der Kamp, Bart	Professor, Forest Sciences, University of British Columbia	31, 37-39, 42	604/822-2728
Wass, Ed	Forest Ecology Research Technician, Pacific Forestry Centre	40	250/363-0600
Wells, William	Soil Scientist, Appropriate Forestry Services Ltd., Kaslo	5	250/366-4482
White, Ken	Contact: John Muir, BCMOF	41	250/387-8740
Woods, Alex	Regional Pathologist, BCMOF, Prince Rupert Forest Region	42	250/847-7500
Wright, D.	Forest Health Technician, BCMOF, 100 Mile House Forest District	43	250/395-7871
Xiao, G.	Associate Professor, Soil Science Department, UBC	2	604-822-4458

Table B. Standard format of summaries.

Headings	Sub-Headings	Description
Project	-	-
Authors	-	-
Study Objectives	-	-
Overview	Site Description	Presented in table format - General location, site and stand characteristics, pre- and post-treatments.
	Layout and Treatments	Site selection criteria, experimental design (e.g. ANOVA), number of replicates.
	Measurements	Parameters measured and techniques used; classification codes.
	Analyses	Proposed statistical analyses and data presentation.
History/Time Table	-	Progress by year.
Status	-	Ongoing or completed.
Brief Summary of Results	-	Presented by objective.
Publications	-	Listed, if any.
Maps	-	Provided only for long-term studies.

2.2.2 Documentation Limitations

Limitations in the documentation provided by contacts restrict project comparisons and/or broader extrapolation of project results. Document limitations are not universal to all projects, but at least one or more of the limitations are characteristic of many projects. In part, this reflects the original exploratory nature of the early studies, with pathology as the primary investigative focus.

These limitations of the documentation include:

Site Information. Information was unavailable for several categories, including the following pre-treatment site characteristics:

- — BEC subzone and site series;
- — slope;
- — aspect;
- — soil classification;
- — stand age or age class;
- — stems/ha (total and well spaced);
- — species composition or forest cover; and
- — Armillaria incidence, by species.

Study Design. Limited reporting on design and site-selection criteria; absence of controls and/or pre-treatment Armillaria incidence/severity; limited or no between-site replication; non-random site and/or plot selection.

Measurements. Limited documentation on pre-treatment stand characteristics (e.g. stems/ha, dbh, insect damage); variable plot sizes; poor documentation or inconsistent reporting of above-ground symptoms used to identify Armillaria root disease (e.g. mycelium, foliage symptoms); and variable use of pathological terms such as incidence and severity (e.g. % of pixels, total number of stems affected, number of stems affected per species, presence/absence, plot ranking).

Analysis. Generally, analyses were poorly documented.

Publications. Few peer-reviewed working plans; few interim reports.

3.0 Overview of the Project Summaries

3.1 Synthesis

In total, 44 operational and research projects were summarized (Table D). While not exhaustive, the list of trials contains the majority of historical and/or ongoing projects conducted in the BC up to 1995. The breadth of these studies provides a solid foundation for developing future research. Many of the short-term studies provide exciting insight into the complexity of the host-pathogen-environment interactions (e.g. Summaries 2, 3, and 42). Other, longer term studies will provide much needed information on 5- and +10-year response to management options (e.g. Summaries 7 and 21). Other projects provide important background information for future planning of operational risk-management trials (e.g. Summaries 30 and 41).

Table C provides a broad overview of the Armillaria projects by topic area. Projects under specific topic areas are further subdivided by biogeoclimatic zone, allowing for a preliminary examination of project representation by environmental factors; the latter are expected to vary considerably within individual zones. Biogeoclimatic subzone/variant and site series are the more appropriate units for classifying site environmental factors because they incorporate the local climatic, physiographic, and soils and vegetation factors.

Based on Table C, the largest number of studies fall under the following two general topic areas:

1. Treatments to control *Armillaria ostoyae* in the IDF (three of six IDF subzones[2]), ICH (four of seven ICH subzones[3]), and SBS (three subzones[4]) biogeoclimatic zones focusing on host mortality and disease incidence.

2. Various aspects of root disease biology and host resistance.

Research topics with limited representation include:

- interactions between host resistance, disease virulence, and environmental factors;
- ecological role(s) of Armillaria species in forest ecosystems;
- various alternatives to mechanical treatments in managed stands;
- growth and yield response in natural and treated stands;
- risk assessment;
- cost-benefit analysis; and
- modelling.

Currently, replication under any topic area is relatively limited. At a minimum, research trials need to be replicated at the zone and, ideally, at the subzone/variant level. Given the broad range of topic areas, and future financial and labour constraints, new trials will need to incorporate aspects of the less well-represented topics whenever possible. This will require integrated projects and collaboration between professionals working in several disciplines. These multi-disciplinary studies should ensure standardization of basic pre- and post-treatment measures, and be designed to facilitate extrapolation beyond the immediate research sites.

3.2 Future Research Needs and Recommendations

As mentioned above, further replication is required under all topic areas; however, special attention should be given to representation in the following topics:

1. Distribution of pathogen virulence and host resistance in managed and unmanaged stands by biogeoclimatic subzone/variant (based on a random and proportional sampling design).

2. Effectiveness of mechanical and alternative treatments in controlling Armillaria root disease, with compulsory growth and yield and cost/benefit analysis components.

3. Host physiological response to Armillaria root disease infection.

4. Ecological role(s) of Armillaria in natural and managed stands and interaction of Armillaria with other forest health agents (fire, insects, disease, and wildlife).

5. Modelling of Armillaria root disease in managed and unmanaged stands.

Many of these topics are inter-dependent and form the framework for developing risk-rating decision tools for forest management activities.

At the individual study level, the following steps are required to ensure results from different trials are comparable:

- document pre-treatment site characteristics, pathogen incidence and assessment method, and stand information that may influence disease expression (refer to Section 2.1.2);
- adopt standard "above-ground" Armillaria identification codes;
- use standard pathological terms, e.g. incidence, severity;
- use standard plot sizes for specific objectives, i.e. where possible;
- document methods and proposed statistical analyses in detail;
- ensure work plans are complete and peer reviewed;
- document methods of Armillaria species verification; and
- ensure working plans are completed and peer reviewed prior to project start-up.

The study objectives, i.e. whether for operational demonstration purposes or experimental purposes, will determine design considerations such as replication, representation, and site and plot selection. Extrapolation of results beyond the existing sites requires random site selection (within the framework of site-selection criteria) and replication by ecosystem type or other key factor(s) which are identified as potentially influencing disease expression. Many of the current studies locate plots over identified (randomly selected) disease centers, with the objective of documenting host-pathogen response in areas with originally high disease incidence. These studies will need to be complemented by studies that provide for random dispersion of plots to meet objectives of describing host-disease treatment response at the stand and landscape management unit level (van der Kamp 1993; Filip and Schowalter 1993).

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[2] Summary 21 - IDFdk; 42 - IDFmw; 43 - IDFdk; 20 - dm; 37 - mw.

[3] Summary 7 - mw, mk; 19 - mk; 20 - mw; 21 - mw (3); 22 - mw; 23 - mw; 25 - wk; 28 - mk; 29 - mm; 35 - mw; 42 - mw.

[4] Summary 8 - dw; 39 - mh; 43 - dw.

To facilitate the above, it is recommended that the Armillaria Research Working Group:

1. Prepare a document that:

   - specifies minimum pathogen, stand, and environmental data requirements, both pre- and post-treatment, for all major topic areas;
   - specifies standard above-ground Armillaria identification codes[5] and pathological terms;
   - specifies minimum requirements for plots;[6] and
   - provides examples of common data analyses.

2. Provide support for statistical and peer review when requested.

3. Prepare a document that compiles comments from the Results part of each main Summary in this document by topic to ensure unpublished preliminary results and study limitations identified by the author(s) are taken into account prior to the development of complementary research.

4. Compile information on commonly cited historical studies such as the "Potato Patch"[7] where documentation is very limited.

5. Systematically examine research from the United States and elsewhere to document similarities and differences in methods currently used in BC and to identify which research has direct application to BC ecosystems.

6. Update this document every three to five years.

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[5] For example, J. Beale, G. Davis, D. Morrison, and J. Pollack. 1994. Recommended standards for establishing and monitoring root disease permanent sample plots. Draft internal document. Nelson Forest Region. BCMOF.

[6] See preceding Footnote.

[7] Although this site in the Kamloops Forest Region is undocumented, it is commonly referred to by Armillaria researchers.

Table C. Summary of BC trials by topic area and biogeoclimatic zone, identified by Summary number.

			Biogeoclimatic Zone [c]								
Main topic	Sub-topic	General [a]	PP	IDF	ICH	MS	ESSF	SBS	CWH	MH	Total no. summaries
		(Summary #)									
A. General root disease biology	i. Species/clone identification (haploid/diploid testing)	2, 31, 24		3	3, 14			38	3		six
	ii. General geographic distribution of species	24		3	3, 14				3		three
	iii. Geographic variation in species pathogenicity										—
	iv. Mechanisms of pathogenicity (e.g. genetics)	33									one
	v. Environmental factors influencing pathogenicity and spread				14						one
	vi. Correlation between below- and above-ground symptoms			20	20		20				one
B. Development of new laboratory techniques	i. Routine species/ clone/genotype identification										—
	ii. Inoculation	2, 31									two
C. Host resistance (by species)	i.. Physiological mechanisms (chemical/physical)	31		3, 20	3, 20		20		3		three
	ii. Genetics										—
	iii. Environmental factors influencing host susceptibility			3	3				3		one
D. Armillaria expression in unmanaged stands	i. Distribution(d), incidence(i), severity(s), rate of spread(r)			15 (i) 42 (i,s)	14 (d,i) 15 (i) 42 (i,s)			38 (d,s,m)			four
	ii. Environmental factors influencing expression			42	42, 14						two

Table C, continued.

			Biogeoclimatic Zone ^{c}								Total no. summaries
Main topic	Sub-topic	General ^{a}	PP	IDF	ICH	MS	ESSF	SBS	CWH	MH	
		(Summary #)									
E. Ecological role of Armillaria	i.. Decomposition/ nutrient cycling										—
	ii. Wildlife habitat				34						one
	iii. Successional processes										—
	iv. Forest health interactions (disease, insect, fire)			15	15						one
F. Detection survey methods	i. Routine operational	16									one
	ii. Stage sampling - aerial photography/field sampling	30			9						two
	iii. Others										—
G. Inventory	i. Management units				11						one
	ii. Landscape/drainage scale										—
	iii. Regional scale	41			11						two
H. Risk assessment	i. Management unit based	30									one
	ii. Ecosystem based	17									one
I. Treatments in managed stands: distribution (d), incidence (i), mortality (m), rate of spread (r), G & Y (g), with control (c)^{b}	i. Conventional clearcut			42 (i,m)	7 (d,i,m,r,g,c) 22 (d,i,m,r) 28 (i,m,c) 29 (i,m) 42 (i,m)						five
	ii. Pop-up clearcut	4 (i,c)			7 (d,i,m,r,g,c)						two
	iii. Stumped clearcut	4 (i,c) 13 (i,c) 36 (i)		43 (m,i)	19 (i,m,c) 23 (i,m,c) 35 (i,m,c)			39 (i,m,c) 43 (i,m)			eight
	iv. Conventional pre-commercial thinning/brushing	32 (i,c)		20 (i,c) 37 (i,m,c)	7 (d,i,m,r,g,c) 20 (i,c) 25 (i,m,g,c) 42 (i,m)	1 (i,m)	20 (i,c)	8 (m)	44 (i,m,r,g,c)		nine

Table C, continued.

			Biogeoclimatic Zone [c]								Total no. summaries
Main topic	Sub-topic	General [a]	PP	IDF	ICH	MS	ESSF	SBS	CWH	MH	
		(Summary #)									
I., continued	v. Pop-up pre-commercial thinning/brushing	32 (i,c)		21 (i,m,r,c)	7 (d,i,m,r,g,c) 21 (i,m,r,c)	21 (i,m,r,c)			21 (i,m,r,c)		three
	vi. Conventional patch cut										—
	vii. Pop-up patch cut										—
Other aspects	viii. Harvesting damage influencing expression				7, 1	1					two
J. Alternatives to stump removal	i. Alternate conifer species		43	37, 42	7, 10, 19, 23, 42			39, 43			eight
	ii. Alternate deciduous species				10			39			two
	iii. Fallow										—
	iv. Biological controls			2							one
	v. Chemical controls			2							one
K. Operational cost evaluation	i. Stumping	6			26						two
	ii. Pushover clearcut	6									one
	iii. Pushover pre-commercial thinning										—
	iv. Alternatives										—
L. Modelling [d]	i. Testing (i) or development (d)										—
M. Cost benefit analysis	i. Stumping	18									one
	ii. Pushover clearcut										—
	iii. Pushover pre-commercial thinning										—
	iv. Alternatives	18									one

Table C, continued.

			Biogeoclimatic Zone [c]								Total no. summaries
Main topic	Sub-topic	General [a]	PP	IDF	ICH	MS	ESSF	SBS	CWH	MH	
		(Summary #)									
N. Soil disturbance (physical disturbance & loss of soil organism habitat)	i. Stumping	5, 40			10, 26						four
	ii Pushover clearcut	5		27	27						two
	iii. Pushover pre-commercial thinning										—

[a] General = lab or field trial where zone not specified. [b] Control - may refer to untreated or clearcut control plots. [c] PP= ponderosa pine. IDF=Interior Douglas-fir. ICH=Interior cedar hemlock. MS=montane spruce. ESSF=Engelmann spruce subalpine fir. SBS=sub-boreal spruce. CWH=Coastal western hemlock. MH=mountain hemlock. [d] BCMOF is continuing to revise the model PROGNOSIS although no specific report was available at the time this document was compiled.

4.0 Summaries of Individual Armillaria Research Projects in BC, 1975-95

Table D. List of project titles by summary number, author, and page number.

Summary no.	Author(s) or Contacts	Project / Title	Page no.
1	Allen E., Morrison D.	Armillaria root disease dynamics in lodgepole pine stands spaced to reduce mountain pine beetle hazard	13
2	Chapman B., Xiao G.	Biological control and cultural control of Armillaria root rot	19
3	Cruickshank M.	Effects of pre-commercial thinning on *Armillaria ostoyae* root rot	24
4	Darbyshire & Sons (D. Norris)	Columbia West Road stumping trial for control of Armillaria root disease	31
5	Davis G., Wells W.H.	Stumping and pushover logging in the Nelson Forest Region, 1992 and 1993 soil disturbance surveys	33
6	De Long D.L.	Review of five time and motion studies completed on root removal treatments in the Nelson Forest Region	36
7	De Long D., Pollack J., Quesnel H., Thompson C.	Partial cutting in *Armillaria ostoyae* and *Inonotus tomentosus* infected stands	40
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[a] Summaries are ordered alphabetically by the first author's surname.

SUMMARY 1

Project
FRDA FC-FR04

Armillaria Root Disease Dynamics in Lodgepole Pine Stands Spaced to Reduce Mountain Pine Beetle Hazard

Author(s)

E. Allen and D.J. Morrison

Study Objectives

1. Measure the endemic levels of Armillaria in two lodgepole pine/larch stands in the east Kootenays.

2. Assess Armillaria infection levels and the rate of Armillaria development in lodgepole pine stumps following spacing and clearcut operations.

3. Determine whether spacing operations predispose live lodgepole pine to Armillaria infection through the release of latent Armillaria lesions to an active growth state.

4. Establish baseline measurements of injury incidence and severity for long-term assessment of wound-related decay in lodgepole pine.

5. Quantify mortality of natural and planted regeneration due to Armillaria infection in thinned and unthinned lodgepole pine stands.

Overview

Layout and Treatments

See Table 1-a for site descriptions.

This study is a component of a research project evaluating the effect of different thinning densities and fertilization on mountain pine beetle (IBM) population dynamics (FC-FR04). The IBM study is ongoing on two sites and includes four treatments: control, 4x4 spacing, 5x5 spacing, and clearcut.

The mountain pine beetle project was initiated in 1992, with spacing undertaken in 1993. Each treatment was undertaken in an area of 0.5 to 1 ha. Within each area two 100x100-m plots were established for the IBM monitoring. One of the replicates was fertilized, the other was not.

The Armillaria plots were installed in the summer of 1994, 1.5 years after spacing. At both sites, five 20x20-m plots (0.04 ha) were permanently established within the buffer surrounding the IBM 100x100-m plots. Two plots were randomly located in the clearcut, and one plot in each of the 4x4-m and 5x5-m thinning and control treatment areas, i.e. outside the mountain pine beetle plots.

Measurements

Objectives 1 and 2: Endemic Armillaria levels and rate of Armillaria inoculation of stumps

In each Armillaria study plot, stumps and trees were mapped and tagged. Stumps were removed from the ground using a LinkBelt excavator. Information recorded on the stumps included: species, presence of Armillaria species, and location and size (lineal growth along root) of lesions and fans in the clearcut and spaced plots.[8] In the control plots an above-ground assessment for symptoms of Armillaria infection (i.e. mycelial fans, basal resinosis) will be made of each tree prior to felling. Armillaria species are being identified using PCR-RFLP analysis.

Objective 3: Injury-related predisposition to Armillaria

Within each of the non-fertilized thinning treatments, ten trees with injuries and ten without were randomly selected for study outside the 100x100-m and 20x20-m permanent plots. Trees were felled and the roots excavated. Prior to felling, the following parameters were recorded: species; dbh (cm); height (m); crown class; and injury symptoms in terms of size, severity, and height from the ground. The stumps were examined for number and location of new infections, i.e. lesions and mycelial growth; and active mycelial growth from lesions present before thinning. Pre-felled stems were also assessed for beetle attack. Sample trees were not initially stratified for Armillaria incidence.

Objective 4: Injury incidence and severity

Twenty trees with logging-related injuries in each of the 4- and 5-m treatment blocks will be tagged; injuries will be measured, categorized, and photographed. A plot map will be produced indicating the approximate location of tagged trees. If resources are available, injuries will be re-measured in 1999, 2004, and 2009, at which time six to seven trees in each spacing treatment will be felled and dissected to determine extent of decay.

Objective 5: Regeneration mortality

Permanent sample plots will be established in clearcut, 4x4, and 5x5 and control treatment stands to survey advanced, planted, and natural regeneration (information on size and location of plots unavailable). If resources are available, surveys will be conducted in Years 3 and 5 to determine mortality due to Armillaria infection. Plots will continue to be monitored for 10 and 15 years.

Analyses

Objectives 1 and 2: Endemic Armillaria levels and rate of Armillaria inoculation of stumps

At each site, the five 0.04-ha plots will be treated as pre-treatment replicates. Data presentation will include number of infected root systems/plot as a percentage of the trees (stumps), percentage of trees (stumps) with Armillaria, correlation between above- and below-ground signs and symptoms (control plots only), and comparison of lesion characteristics in the cut and control plots. The control plots will serve as a baseline of lesion activity in the absence of cutting.

Objective 3: Injury-related predisposition to Armillaria

Summary statistics will include the following by treatment and injury class: percentage of trees with new infections, percentage of trees with active mycelial growth from pre-existing lesions, and estimates of the potentially infective area surrounding stumps on the basis of linear measurements of mycelial growth on roots.

Objective 4: Injury incidence and severity

Summary statistics will include size, severity and location of injuries, and ultimately decay associated with injuries.

---

[8] It is expected that Armillaria lesions that were inactive prior to falling will have started actively growing in the 1.5 years since spacing.

Objective 5: Regeneration mortality

Summary statistics will include the Armillaria-related mortality of natural and planted regeneration stock.

History/Time Table

January 1993	Thinning treatments completed.
Summer 1994	Armillaria plots established, stumps excavated, and Armillaria incidence data collected. Injured trees documented.
Summer 1995	Permanent sample plots established to monitor regeneration mortality.
1999	Tree injuries and regeneration mortality re-measured.
2004	Tree injuries and regeneration mortality re-measured.
2009	Tree injuries and regeneration mortality re-measured.

Status

Ongoing.

Brief Summary of Results

Data analysis is currently ongoing. The following general statements can be made regarding Armillaria species distribution at the study sites:

- Very little Armillaria was found in any of the plots at the Cranbrook sites (Objectives 1 and 2). The only Armillaria found was on stumps in one of the clearcut plots.
- Armillaria was present in all plots at the Elkford site. Armillaria incidence ranged from ≅ 5% in the control plot to ≅ 72% in the clearcut. Species identification is ongoing. To date only *Armillaria sinapina* has been positively identified (using PCR-RFLP analysis) from root systems of stumps from the original harvest operations.
- No Armillaria was found on the root systems of standing injured or uninjured trees at either site (Objective 3).

Working Plans/Reports/Publications

A draft working plan has been reviewed and revised. No reports or publications, except interim progress reports, have been prepared.

Maps

See following.

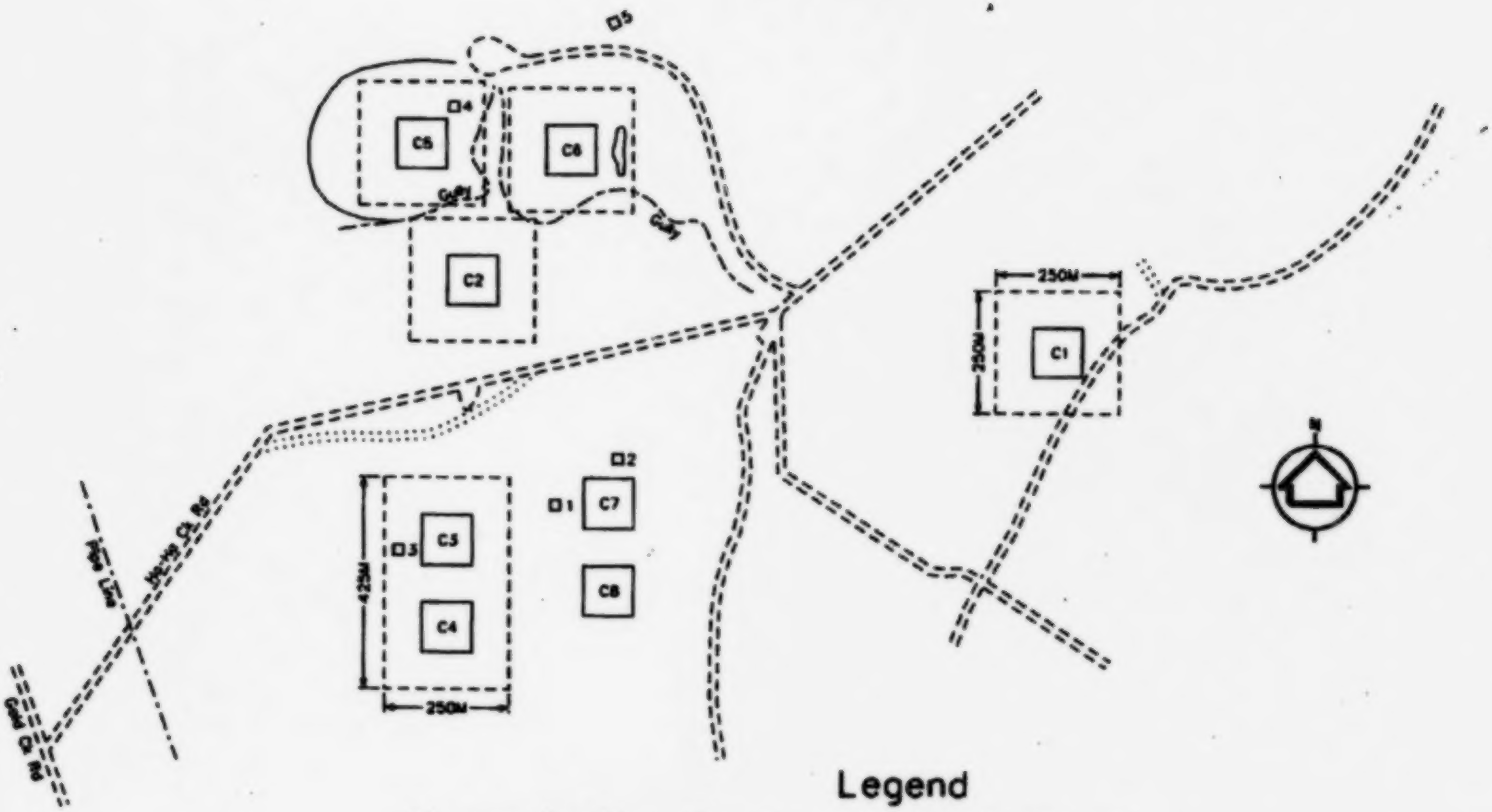
Table 1-a. Site descriptions.

	Site	
	Cranbrook	Elkford
Region	Nelson	Nelson
District	Cranbrook	Cranbrook
Opening No.	82G042-	82J016-007
Plot Lat/Long	49°25'N/114°37'W	50°08'N/114°57'W
Study Area (ha)	18.7	34.5
Biogeoclimatic Subzone/ Site Series	MS dk 04	MS dk 05
Slope (%)	0-20	10-20
Aspect		SE
Species Composition/ Age(y)/Site Class	OS: Pl(L)/age class 4/M	OS: Pl(S)/age class 5/M, Pl/age class 5/M
Stems/ha (no.)	OS: 700	OS: 725
Terrain/Soil Class./Soil Texture	x/x/ fSL/LS	x/x/x
Diseases/Insects	IBM,(DRA)	IBM, DRA
Stand History	fire/ logging	fire
Study Establishment	1993-1994	1993-1994
Treatment(s)	4x4-m and 5x5-m pop-up spacing	4x4-m and 5x5-m pop-up spacing

See Appendix C for abbreviations.

CRANBROOK

SCALE: 1:12500



C1
C2
C3
C4
C5
C6
C7
C8
1
2
3
4
5
250M
250M
250M
425M
Gully
Gully
N
Pipe Line
Gold Ck Rd
Harris Ck Rd

Legend

Mountain Pine Beetle Thinning Study

C1, C2, C9 - Control
C3, C4 - 4x4 spacing
C5, C6 - 5x5 Spacing
C7, C8 - Clearcut

Armillaria Study

1. Clearcut
2. Clearcut
3. 4x4
4. 5x5
5. Control

☐ Treatment Block
⬚ Buffer
== Road
:::: Spur Road

ELKFORD

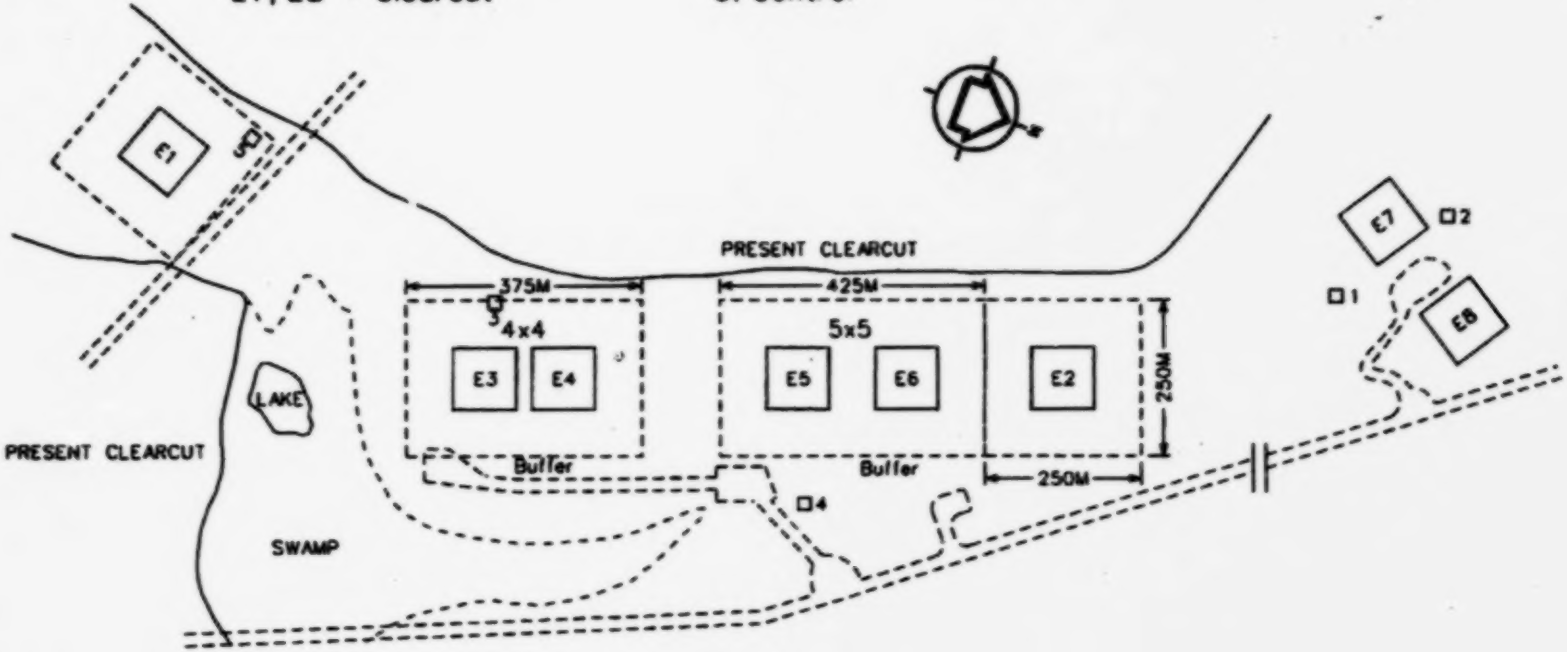
SCALE: 1:10000

Legend

Mountain Pine Beetle Thinning Project
E1, E2 - Control
E3, E4 - 4x4 spacing
E5, E6 - 5x5 Spacing
E7, E8 - Clearcut

Armillaria Study
1. Clearcut
2. Clearcut
3. 4x4
4. 5x5
5. Control

□ Treatment Block
⬚ Buffer
=== Road
::::: Spur Road


E1
5
PRESENT CLEARCUT
LAKE
SWAMP
375M
3
4x4
E3
E4
Buffer
PRESENT CLEARCUT
425M
5x5
E5
E6
Buffer
4
E2
250M
250M
E7
2
1
E8

SUMMARY 2

Project **Biological Control and Cultural Control of Armillaria Root Rot**

Author(s) B. Chapman and G. Xiao

Study Objectives

1. Investigate alternative approaches to controlling *Armillaria ostoyae* root disease.

2. Evaluate the effect of ring debarking of trees on Armillaria aggressiveness, and determine if this technique may be useful for controlling the disease.

3. Identify competitive saprophytic fungi that will reduce or eliminate the spread of *Armillaria ostoyae*, and develop techniques to utilize such fungi on an operational scale.

4. Identify ectomycorrhizal fungi that might protect to seedlings and young trees from *Armillaria ostoyae*.

5. Identify soils that are suppressive to Armillaria, and develop techniques to increase soil suppressiveness.

Overview

Layout and Treatments

See Table 2-a for site descriptions.

Ring-Debarking Trials

Ring-debarking trials were conducted in two phases at three field locations that have been partially cut over the past 20 years and are infected with Armillaria. At each of the three sites, twelve infection centers relatively free of stumps were identified based on the presence of trees with obvious symptoms (e.g. mycelial fans and basal resinosis). Each infection center consisted of 20-40 trees, including some trees measuring >30-cm dbh, and variable amounts of regenerating trees. No information on species composition of the clusters was given.

Phase I. At each of the three sites, six of twelve infection centers were randomly selected for treatment. All trees measuring >1.3-m high were ring debarked in late summer and early fall of 1993. Ring debarking involved cutting away a 10-cm-wide strip of bark from around the circumference of the bole at breast height. Bark was peeled away with a chisel or pry bar. Special care was taken to minimize damage to the xylem during this procedure.

None of the trees in six control treatments per site were ring debarked. At the Young Lake site only, no regeneration ≤2-m high was ring debarked. This modified treatment provided an opportunity to observe the effects of ring debarking of harvested trees on existing regeneration.

Phase II. Half the ring debarked and half the control plots were harvested by horse logging after 1 year. The remaining half were harvested after 2 years. Harvested centers were planted with Interior Douglas-fir the year after harvesting. All trees in controls were harvested and planted in the same manner.

Competitive Fungus Lab Trials

Saprophytic fungi were isolated from several locations in the Cariboo Forest Region. Fungi that establish vigorous infections in stumps and roots—but do not appear to coexist with severe Armillaria infection—or those that are cited in the literature as having good competitive potential were selected. Discs of Douglas-fir root material were separately inoculated with *Armillaria ostoyae* (identified by tester strain plating) that had been isolated from several locations in the Cariboo Forest Region, and with several species of saprophytic fungi. All discs were incubated at 22-24°C until heavily colonized.

Competitive Fungi on Root Segments. Discs were attached to root segments such that an Armillaria-inoculated disc and a disc with one of the saprophytic fungi were at opposite ends of the root segment. The two combinations of Armillaria / saprophytic fungi were replicated a minimum of 20 times. Root segment/disc was placed in a tub of sterilized sand in a plastic container and incubated at room temperature. Controls, consisting of root disc inoculum of the same fungal species at both ends of the root segments, were tested. Root segments were checked for colonization one month after inoculation, and when fully colonized, they were examined under the microscope.

Competitive Fungi on Stumps. Three treatment plots in the ICH at Gavin Lake, and twelve treatment plots and twelve stumped plots in the IDF near Long Lake were inoculated using an inoculation procedure that may be patented. An equal number of control plots were established at each site. At each site, four isolated disease centers consisting of 20 to 40 Douglas-fir trees were identified; controls and treatments were randomly assigned. All trees >10-cm dbh within a disease center were felled. Stumps in treatment centers only will be inoculated, and 40 Douglas-fir seedlings were planted at 1.2 and 3-m radii and 1-m circular spacing around stumps in both treated and control disease centers. Future research will consist of several 20-ha trials, consisting of five controls and five inoculated treatments at each site. Three of these trials will be established in 1996.

Mycorrhizal Fungi Trials

Mycorrhizae will be isolated from young Douglas-fir seedlings, and sterilized; root tips will be planted out onto agar. Fungal colonies will be purified and mycorrhizae-forming isolates will be plated out with isolates of pathogenic Armillaria species obtained from the same site. In addition to *in vitro* trials, all mycorrhizal isolates will be used in pot trials to inoculate seedlings in contact with Armillaria-infected root segments.

Identification of Suppressive Soils. 100 kg of soil will be collected while excavating for fungal isolate collections associated with this study. Soils will be placed in 6-inch pots and planted with Douglas-fir. Infections will be initiated in seedlings by applying root segments inoculated with Armillaria to seedling roots. Any suppressive soils identified during this process will be sterilized and isolated. Antagonistic organisms will also be inoculated in soil collected from around diseased Douglas-fir trees, to examine their suppressiveness. (Further detail on antagonistic organisms is not provided.)

Measurements

Ring Debarking Trials

The Douglas-fir seedlings and natural regeneration in each center will be coded annually as healthy, symptomatic (based on chlorotic foliage, basal resinosis), or dead. The distance of dead, planted, and natural regeneration to stumps will be recorded for each center. Dead trees will be uprooted and the roots described. Further details on root descriptions not provided.

Competitive Fungus Lab Trials

Competitive Fungi on Root Segments. The length of root segment occupied by each fungus will be measured on a weekly basis. The proportion of the total root segment occupied by each fungus will be used as a qualitative measure of the interaction between the two fungi.

Competitive Fungi on Stumps. In the small inoculated plots, the primary measurement is the isolation of fungi from the stumps to monitor the volume occupied by Armillaria versus that occupied by the biocontrol fungus. Seedling survival and incidence of Armillaria root disease are also being monitored. In the large-scale plots, seedling survival and incidence of Armillaria root disease will be monitored annually for up to 20 years.

Mycorrhizal Fungus Trials

Seedling mortality will be monitored, and root systems infected with *Armillaria ostoyae* will be described.

Identification of Suppressive Soils

Measurements taken to determine the effect of suppressive soils on Armillaria in pot trials are not specified.

Analyses

No information provided.

History/Time Table

Spring/Fall 1993	Ring debarking trials initiated, collection of Armillaria and saprophytic fungi.
Winter 1993	Isolation, purification, and identification of competitive fungi; development of inoculation techniques.
Fall 1994	Conventional harvesting of half of ring debarked and control clusters.
	Established competitive fungus field trials; initiated study of inoculation with mycorrhizae and investigation of suppressive soils.
Winter/	
Spring 1995	Established two inoculated stump trials.
Fall 1995	Conventional harvesting of remaining stems in ring debarked and control clusters; planting of Douglas-fir seedlings.
	Established suppressive soil trials, initiated mycorrhizal field trials, evaluated mycorrhizal inoculation pot trials and competitive fungus field trails.
1996-1997	Continue data collection on trials related to ring debarking.

competitive fungi, mycorrhizae, and suppressive soils.

Three larger scale trials will be established in 1996, and another three will be established in 1997.

Status Ongoing.

Brief Summary of Results The stumps inoculated with the biocontrol fungus have 100% of the take of the biocontrol fungus. The biocontrol fungus fruited on most of the inoculated stumps. Many of the fruiting bodies were coming from the bole or roots at some distance from the location of inoculation. In the ring debarking trial, the cambium of the treated trees was dried out and hard; while in the untreated trees, the cambium was fresh and soft one year after harvesting. Rapid spread of Armillaria was not observed through either the treated or control stumps. Much of the cambium in the control stumps was eaten by beetle larvae, and the Armillaria fans were at deeper levels. Monitoring of these trials is continuing.

Working Plans/Reports/Publications Xiau, G. and B. Chapman. n.d. Armillaria biocontrol, working plan. Cariboo Forest Region, BCMOF. Unpublished. 22 pp.

Maps None.

Table 2-a. Site descriptions.

	Site		
	Felker Lake	Hawks Creek	Young Creek
Region	Cariboo	Cariboo	Cariboo
District	Williams Lake	Williams Lake	100 Mile House
Opening No.	x	x	x
Plot Lat/Long	51°55'N/ 121°55'W	52°20'N/ 122°10'W	52°10'N/ 121°00'W
Study Area (ha)	x	x	x
Biogeoclimatic Subzone/ Site Series	IDF dk3 01	IDF dk3 01	IDF dk3 01
Slope (%)	0	0-10	0
Aspect	none	W	none
Species Composition/ Age/ Site Class	OS: x PL: FdPl	OS: x PL: x	OS: x PL: x
Stems/ha (no.)	x	x	x
Terrain/Soil Class./Soil Texture	x	x	x
Diseases/Insects	DRA	DRA	DRA
Stand History	natural selection harvest ~1980	natural selection harvest ~1980	selection harvest ~1980
Year Study Established	1993	1993	1993
Treatment	ring barking of all trees >1.3-m height	ring barking of all trees >1.3-m height	ring barking of all trees >2.0-m height

See Appendix C for abbreviations.

SUMMARY 3

Project

Effects of Pre-Commercial Thinning on *Armillaria ostoyae* Root Rot

Author(s)

M. Cruickshank

Study Objectives

1. Determine the effect(s) of pre-commercial thinning on *Armillaria ostoyae* in two Coastal and two Interior ecosystems.

Overview

Layout and Treatments

See Table 3-a for site descriptions.

Site Selection

Three replicate sites were chosen for study in each of the following biogeoclimatic zones: ICH, IDF, CWH, and CDF. Selection criteria included: uniformity of site characteristics, presence of Armillaria centers and uniform disease expression, stand age between 15 and 25 years, pre-commercially thinned post-1995, and presence of Douglas-fir stumps with root contacts with Douglas -fir crop trees.

During the selection process, sites were examined for the presence of inoculum in thinning stumps. Root contacts were also examined between stumps and crop trees for disease transfer. Sites were stratified into lower, mid, and upper slope positions. Transects were selected in a random fashion in each strata across the slope.

Stump Surveys

The first ten stumps (>7-cm diameter at 150 cm above the ground) within a 4-m wide band along each transect were selected for study.

Stump Excavation (CDF not included in this section)

Selected for study were four to seven Douglas-fir stumps, originating from the pre-commercial thinning with possible root contacts to Douglas-fir crop trees. The stumps were systematically chosen in areas where mortality encompassed the range of stump diameters on site.

Measurements

Stump Surveys

Each sample stump was examined for Armillaria signs (fans and rhizomorphs) by exposing the main lateral roots within 30 cm of the root collar. This step was used to document root disease incidence (i.e. presence/absence). A sample of mycelium from each stump was collected, and later identified to species using biological species mating techniques and rhizomorph morphology *in vitro*. Ecological data collected for each transect included: slope, aspect, elevation, hygrotope, trophotope, humus type, soil texture, and coarse fragment content.

Stump Excavation

Stump roots were excavated with a hand trowel to a 3-mm diameter and inspected for root contacts with crop trees and presence of Armillaria mycelium. Where the disease had spread to crop trees, lesion size (area) was measured as the proximal distance and diameter, and distal distance and diameter, from point of contact. For lesions not completely surrounding the roots or for those colonizing the bole, outlines were traced on paper for calculation of area. Notes were made of crop tree/stump root contacts with no transfer of inoculum. The following distances were recorded:

- stump to contact along crop tree root
- crop tree (at root collar) to contact along root
- stump to crop tree (outer bark to outer bark)
- diameter of stump root and crop tree root at contact, and
- type of contact where 1 = root graft, 2 = good wrap around tight contact, 3 = just touching, and 4 = rhizomorph.

Samples of mycelium were collected from each stump for species identification and from each lesion for intraspecific pairing to ensure that stumps and lesions were of the same genotype.

Crop tree infection symptoms were classified based on bark hypertrophy, resin flow, bark and cambial oxidation, adventitious roots, and callus tissue around lesions due to cambial activity that contained lesions.

Stump volume was calculated as the sum of the volume of main lateral and branch roots and stump bole. Volume calculations were based on the following measurements: distance and diameter of main root laterals and branches (numbered clockwise from north), the diameter of the bole, and the distance of the bole downwards from the soil line. Inoculum volume was calculated as the volume of the root and bole occupied by mycelial fans.

Lesion size was standardized by dividing its size by stump inoculum volume.

Additional information recorded at each stump location included contact crop tree species, height, dbh (at 1.3 m), and general visual health and ecological data (as outlined in the stump survey). Tree volume was calculated based on a cone above 1.3-m and a cylinder below 1.3-m high.

Analyses

Stump Surveys

- Summary statistics of Armillaria species identification by transect line, hygrotope, and biogeoclimatic zone.
- Correlation of stump Armillaria species incidence with hygrotope using logistic regression analysis for Coastal and Interior sites.

Stump Excavation

- Summary statistics of percentage of callus formation by biogeoclimatic zone, incidence of transfer of mycelium across root contacts by biogeoclimatic zone, lesion size standardized by inoculum volume for each biogeoclimatic zone and root contact type.

History/Time Table

January 1994 Project initiated.

	Plots established/sampling underway.
June 1995	Tentative project completion.

Status

Ongoing.

Brief Summary of Results

Stump Surveys

A strong positive correlation was found between Armillaria incidence in stumps and absolute soil hygrotope (moisture regime) for all sites ($r^2 = .79$). Further analysis, however, showed different trends for Coastal and Interior sites.

For Coastal sites, Armillaria incidence in stumps increased 20-80% with increased absolute moisture regime, i.e. moderately dry to fresh, and then decreased 20% for the wetter moisture regimes, i.e. moist to very moist. For Interior sites, Armillaria inoculum incidence increased (≅10 to 90%) with absolute hygrotope from very dry to very moist. It is hypothesized that the different trends between Coastal and Interior sites may reflect differences in winter/spring soil saturation periodicity. The absolute soil moisture regime is indicative of growing season moisture deficits, but may not adequately reflect differences in timing or duration of soil moisture conditions during winter.

Field observations in the CWH sites indicate that *Armillaria sinapina* is the dominant species on fresh sites at mid to lower slopes, especially with coarse-textured soils. These environmental conditions may favour rhizomorph formation giving a selective advantage to *Armillaria sinapina* because of its prolific rhizomorph network. *Armillaria ostoyae*, on the other hand, is the dominant species upslope on slightly dry sites. In the ICH, CDF, and IDF, field observations suggest that *Armillaria ostoyae* is the dominant species on all sites with low to moderate abundance of *Armillaria sinapina* on the moist to very moist sites. All field species identifications are being verified by laboratory mating tests.

Stump Excavation

When lesion size was standardized by dividing size by stump inoculum volume, the largest lesions for roots just touching were found in the ICH followed by the CWH and IDF (Table 3-b). Lesions at root grafts were largest in the IDF. In the CWH, the standardized lesion size was not significantly different for just touching versus grafted roots. Root grafts appear to be important for disease transfer in the IDF but not in the CWH.

Other Results

- Mean tree volume was three times greater in the CWH than in the ICH, and four times greater than in the IDF zones.
- The proportion of infected roots showing callus decreased in the following order: CWH (62%) > ICH (18%) > IDF (9%).
- Mean inoculum transfer rates at root contacts were 61, 54, and 60% for the ICH, IDF, and CWH zones, respectively.
- Trees in the IDF and ICH appear to be the most susceptible to disease caused by inoculum spread following thinning. This may reflect the low

proportion of lesions showing callus, high presence of *Armillaria ostoyae* in stumps, and the lower vigour of the trees. The greater size and vigour of trees in the CWH relative to the IDF and ICH zones may account for the high rate of callus formation observed in the former zone.

Working Plans/Reports/ Publications

Cruickshank, M. 1996. Incidence of Armillaria species in precommerical thinning stumps and spread of *A. ostoyae* to adjacent Douglas-fir trees. Simon Fraser University. Burnaby, BC. MDM thesis.

Maps

None. Sites are temporary.

Table 3-a. Site descriptions.

	Site						
	Craigallachie	Larch Hills	Johnson Lake	Brookmere	Lillooet	Maple Mt. #1	Maple Mt. #2
Region	Kamloops	Kamloops	Kamloops	Kamloops	Kamloops	Vancouver	Vancouver
District	Shuswap	Shuswap	Kamloops	Merritt	Lillooet	Duncan	Duncan
Opening No.	014	039	051	062	01		
Plot Lat/Long							
Area (ha)							
Biogeoclimatic subzone	ICH mw3	ICH mw2	ICH mk1	IDF dk2	IDF dk2	CDF trans to	CDF
Site Series	01	01(05)	01(04)	01(05)	04	CWH01(07)	0(02)
Slope (%)	flat	flat	10-20	50	flat	0-5%	2-10%
Aspect	N/A	N/A	S	E	none	W	W
Species Compn./ Age (y)/Site Class	OS: $Cw_6H\ v_3F_1$(Pw)/x/M PL: $F_3Hw_3Cw_2$(Pw)/22/M	OS: $F_6Cw_3H_1$/x/G PL: $F_4Cw_3Hw_1$/27/x	OS: FS/x/M PL: F_6Se_4/23/M	OS: F(Pl)/x/M PL: Fd_7Pl_3/24/M	OS: FS(Cl)/x/M PL: Fd	OS: Fd PL: Fd	OS: Fd/x/x PL: Fd/x/x
Stems/ha (no.)	OS: 5391 PL: 990	OS: 8170 PL: 926	OS: 2640 PL: 825	OS: 2800 PL:	OS: 3100 PL: 750		OS: x PL: x
Terrain/Soil Class./ Soil Texture	x/x/clayey	x/x/loamy	x/x/loamy	x/x/clayey to sandy	x/x/clayey to sandy	x/x/sandy to clayey	x/x/loamy
Disease/Insects	DRA	DRA	DRA	DRA	DRA	DRA	DRA
Stand History	harvested 1970 planted 1971	harvested 1964 planted 1969	burned 1970 planted 1971	harvested 1968 natural regen	harvested 1965 natural regen.	watershed commercial thin	watershed commercial thin
Study Establishment	1993	1993	1993	1993	1993	1993	1993
Treatment(s)	thinned: 1988	thinned: 1989	thinned: 1988	thinned: 1990	thinned: 1988	thinned: 1988	thinned: 1988

See Appendix C for abbreviations.

Table 3-a, continued. Site descriptions.

	Site						
	Nanaimo Lakes	Callaghan	Squamish #1	Squamish #2	Butler	Rutherford Creek	Picture Valley
Region	Vancouver	Vancouver	Vancouver	Vancouver	Vancouver	Vancouver	Nelson
District	Duncan	Squamish	Squamish	Squamish	Duncan	Squamish	Cranbrook
Opening No.	F009 2219	144	50-50	43-53	30-41 and 50-41	16	17
Plot Lat/Long							
Area (ha)							
Biogeoclimatic subzone/ Site Series	CWH xm1 x	CWH ms x	CWH ms x	CWH ds x	CWH mm1 x	CWHds 03(07)	IDFdm2 03(04)
Slope (%)	20-30%	10%	0-45%	0-30%	5-30%	5-45%	10-40%
Aspect	NW	W	S	S	E	S	E
Species Compn./	OS:$H_6F_2C_2$ /x/x	OS: F(H)/x/x	OS:F_7C_3/x/x	OS:$F_8C_1H_1$	OS:$H_4F_4C_2$	OS: FBl/x/x	OS:F(Py)/x/x
Age(y)/Site Class	PL:$H_5F_3C_{2/x/x}$	PL: x/x/x	PL: x/x/x	PL:$F_7C_2P_1$(H)	PL:$F_7H_2C_1$	PL: x/x/x	PL: x/x/x
Stems/ha (no.)	OS: 15021	OS: x	OS: 1408	OS:2532conifer	OS:5560	OS: x	OS: x
	PL: 10507	PL: x	PL:648	2565 decid PL:600	PL:600	PL: x	PL: x
Terrain/Soil Class./Soil Texture	x/x/loamy	x/x/loamy	x/x/loamy to sandy	x/x/sandy to silty	x/x/clayey to loamy	x/x/loamy to sandy	x/x/sandy to clayey
Disease/Insects	DRA	DRA	DRA	DRA	DRA	DRA	DRA
Stand History	harvested 1968; planted 1968	harvested 1971 planted 1973	harvested 1966 burned 1968 planted 1969	harvested 1966 burned 1966 planted 1967	harvested 1965 planted 1966	harvested 1961 burned 1961 planted 1965	natural regen selective harvest
Study Establishment	1994	1994	1993	1993	1993	1994	1994
Treatment	thinned: 1990	thinned: 1989	thinned: 1992	thinned: 1987	thinned: 1988	thinned: 1992	thinned: 1987

See Appendix C for abbreviations.

Table 3-b. Mean standardized lesion size.

	Biogeoclimatic Zone		
	ICH	IDF	CWH
Roots touching mean (SE)	0.24 (0.04)	0.02 (0.01)	0.13 (0.01)
Root grafts mean (SE)	none	0.46 (0.18)	0.13 (0.04)

SUMMARY 4

Project
Pest Control Project 61

Columbia West Road Stumping Trial for Control of Armillaria Root Disease

Author(s)

Darbyshire and Sons

Study Objectives

1. Assess a root removal trial at C.P. 108, Columbia West Road to determine the amount and kind of roots left after stumping, and the degree of site disturbance for the four treatments.

Overview

Layout and Treatments

A root disease stumping trial was performed in 1987 by Evan Products of Golden on a site with a high incidence (15.7%) of Armillaria. Four treatments were employed on the most heavily infected area (4.5 ha) within a 33.5-ha cutblock: pushover logging with a 235 backhoe, stumping with a 235 backhoe/thumb attachment, stumping with a crawler-tractor, and control.

Measurements

Pre-Treatment

Details on pre-treatment measures were not provided in the Pest Control Project 61 summary (1990).

Post-Treatment

In 1988-89, 17 sample pits were randomly selected in these treatment units, and excavated using a 580S-type backhoe. Pits, 1-m^3 in size, were excavated and examined for root residues in the upper and lower 0.5-m layers of each pit. Four diameter and length classes were used to classify root material recovered. Both Armillaria- and Tomentosus-infected roots were identified and separated for data analyses, but very few roots in the trial areas contained the latter disease.

History/Time Table

October 1988 Root excavation.

Status

Complete.

Brief Summary of Results

Crawler-tractor stumping and pushover logging were found to be almost equally effective in removing total root material at 76% and 69% respectively. However, consistently less infected root material was left during pushover logging. Backhoe stumping resulted in twice as many infected roots being left in the soil. Backhoe stumping left infected stumps because of high slash levels and low visibility. Site disturbance was unacceptably high with the crawler-tractor, but was much less with the backhoe. Pushover logging appeared to produce the best results in terms of low site disturbance and amount of infected material removed from the site.

Contractor's Recommendations

- Ensure that control blocks are uniform, perhaps by means of a pretreatment root survey.
- Remove slash before treatment to ensure that all infected stumps are removed.
- Do not use crawler-tractors for stumping because this equipment causes excessive site disturbance.
- Pushover logging with some yarding refinements is probably the best technique for most Interior sites and, thus, should be further assessed.

BCMOF (1990) Comments

The control area selected for this trial assessment was probably not representative of the rest of the site. Further, additional pits could not be excavated due to funding constraints. However, preliminary results indicate that pushover logging was probably the best treatment because more duff was retained and relatively few infected root pieces remained in the soil. Further root removal trials and residue assessments should ensure that the control area is representative. In addition, more sample pits should be dug per treatment unit in order to have a truly representative data set. These concerns aside, further assessments of Armillaria control trials should be conducted because excavations for root residues will probably give a reasonable indication of the effectiveness of various stumping methods.

Working Plans/Reports/ Publications

Norris, D. 1988. Columbia West Road: Root removal trial. BCFS Internal Report (Pending). 13 pp.

Taylor, B. 1988. An analysis of some various stumping trials for the treatment of Armillaria root disease in the Golden Timber Supply Area. 36 pp. (Related non-FRDA Report)

Maps

None.

SUMMARY 5

Project

Stumping and Pushover Logging in the Nelson Forest Region, 1992 and 1993 Soil Disturbance Surveys

Author(s)

G. Davis and W.H. Wells

Study Objectives

1. Summarize and discuss the 1992 and 1993 Armillaria treatment soil disturbance surveys with respect to MSP disturbance categories, total potentially detrimental soil disturbance, and total soil displacement.

2. Provide interim direction to District staff in assigning total potentially detrimental disturbance maximum levels on PHSPs for operational treatment units designated for stump removal.

3. Identify immediate research needs to characterize and quantify soil disturbance created by stump removal.

Overview

Layout and Treatments

Refer to report for site description information.

Candidate study sites were selected by District staff of the Ministry of Forests. Given the relative "newness" of these treatments, the three main selection criteria were that:

- operations represented an average or better than average (i.e. benchmark) level of planning and execution;
- site characteristics fell within those specified in Armillaria Sensitivity Considerations, Appendix A, of the *Interim Guidelines for Armillaria Management in the Nelson Forest Region* (NFRS 1994);[9] and
- operations were conducted in summer and winter.

Site factors identified in Appendix A, to restrict stump removal to less sensitive sites, included: slopes >30%; carbonates <30-cm deep; clayey soils; unfavourable subsoils (<45-cm deep); seepage (<60-cm deep); and high surface erosion, mass wasting, and forest floor displacement hazards.

Eight treatment units were surveyed in 1992, and eleven in 1993. In total, five were stumped, two in summer and three in winter; and fifteen were pushover logged, eight in summer and six in winter.

Measurements

Soil disturbance was measured using the grid-point intercept method (Curran and Thompson 1991).[10] Standard timber harvesting and mechanical site preparation disturbance categories were recorded. In addition, each point was double coded for stump holes. The stump hole disturbance category included three subdivisions based on depth and width criteria.

In addition to soil disturbance, the following information was collected: site characteristics such as soil texture, terrain, terrain complexity, slope; soil disturbance hazards; silviculture system; and stump removal/harvesting operations (i.e. method, equipment, pattern of skidding).

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[9] Upon review of the sites, only a small portion met the Appendix A criteria.

[10] Method of sampling changed between 1992 and 1993, and differences are described in Davis and Wells (1994).

Analyses

Summary statistics, comparison tables, and graphs were used to analyze site total detrimental disturbance and total soil displacement by treatment and season. The limited number of replicates by treatment, season, and site prevented a detailed evaluation of factors responsible for observed differences.

The *Interim Soil Conservation Guidelines for Mechanical Site Preparation* (BCMOF 1993) was used to set the maximum total detrimental and total displacement values. Guideline maximums for total soil displacement ranged from 15 to 30% of the Net Area to be Reforested (NAR), depending on site sensitivity.[11] The maximum total displacement ranged from 15 to 40% of NAR, depending on site sensitivity.

In the assessment, only two of the three stump hole categories counted as detrimental disturbance, while all stump holes contributed to total displacement.

History/Time Table

Completed.

Status

Completed.

Brief Summary of Results

Stumping

Five stumping blocks were surveyed (two summer and three winter treatments). Detrimental disturbance levels ranged from 12.1% to 22% of NAR. In general, stumped treatments had a higher portion of wide gouges at the stump holes than pushover treatments.

Summer Pushover

The eight summer pushover blocks surveyed had detrimental disturbance levels ranging from 6.7 to 36.3% of NAR. Total soil displacement values ranged from 14.5 to 54.7%. Blocks with lower detrimental disturbance levels also had the lowest total soil displacement levels.

Winter Pushover

Six blocks were surveyed. One block had a high soil displacement hazard, so the allowable levels of detrimental disturbance and total displacement for this block were 6% and 13%, respectively, and outside the recommended sensitivity guidelines for this treatment. For the remaining five blocks, the detrimental disturbance levels ranged from 6.6% to 14.2%. Four blocks met the 30% total displacement guideline maximum, with the fifth block being slightly over at 33.4%.

Stumping versus Pushover Logging

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[11] Disturbance numbers were tallied for the Net Area to be Reforested (gross cutblock area minus haul roads and landings).

Most of the sampled blocks met or came close to the total allowable soil displacement guidelines, except blocks which were summer pushover logged. Fifty percent of these blocks had unacceptable levels of soil displacement.

Winter pushover logging was the only treatment type that met maximum allowable levels of detrimental disturbance. There was little difference in summer pushover and stumping treatments, and both were higher than the winter pushover treatment.

Stumping resulted in higher levels of stump hole disturbance, particularly holes large enough to be considered wide gouges. Summer pushover logging resulted in higher levels of harvesting-related disturbances than either winter pushover or stumping.

Winter pushover logging had the lowest levels of non-stump-hole disturbances (gouges, scalps, etc. not located at stump holes).

Recommendations

1. Restrict stump removal to sites meeting criteria set out under Appendix A, *Soil Sensitivity Considerations.*

2. Favour pushover logging over stumping - sensitive sites should be worked in winter.

3. Include a high level of pre-harvest prescription planning in operational stump removal treatments.

4. For operational treatment units designated for stump removal in 1994/95, consider approving PHSP total potentially detrimental disturbances of up to 20% during harvesting, with the requirement for planned rehabilitation of skid roads post- harvest, with the objective of reducing post-harvest total detrimental disturbance as close to 13% as possible.

5. Allow time for additional evaluation by phasing in use of stump removal as an operational tool.

6. Develop a regional soil disturbance survey program to coordinate and summarize soil disturbance monitoring on a range of site sensitivities.

7. As future data become available, complete a review of:

   - disturbance categories used to characterize stump removal disturbance,
   - dimensions and categories considered pushover potentially detrimental or excessive, and
   - potential "trade-offs" of stump removal in terms of organic matter, nutrient and habitat losses, by biogeoclimatic subzone and site series.

Working Plans/Reports/ Publications

Davis, G. and W.H. Wells. 1994. Stumping and pushover logging in the Nelson Forest Region, 1992 and 1993 soil disturbance surveys. Nelson Forest Region, BCMOF. Tech. Report TR-009.

Maps

None.

SUMMARY 6

Project

Review of Five Time and Motion Studies Completed on Root Removal Treatments in the Nelson Forest Region

Author(s)

D.L. De Long

Study Objectives

1. Summarize the time-and-motion trials that have been completed on root removal treatments in the Nelson Forest Region.

2. Determine if further time-and-motion information on root removal treatments is required, and, if so, recommend standards for future studies.

Overview

See Table 6-a for site descriptions.

The report provides a retrospective analysis of five time-and-motion studies. Only three studies are discussed in detail. Table 6-b summarizes the elements of each of these three trials.

History/Time Table

Completed.

Status

Completed.

Brief Summary of Results

Knappen Creek (Nazaroff 1989 1990)

The average time for the excavator to remove a stump increased with diameter class, for an overall average of 1.09 sec/cm of diameter. Stumping costs were $1463 in 1989 and $1213/ha in 1990. The lower costs in 1990 were attributed to fewer stumps, fewer residual trees, and piling of slash prior to stumping. The results of this study are used by the Valuation Section (Nelson Forest Region) as a basis for cost estimates for root removal treatments to add onto the appraisal allowance (further detail provided in report).

Stewart Creek (Toews and Nazaroff 1991)

This was the first time-and-motion study of a pushover falling operation conducted in the province. The cost estimates were $5618/ha or $\$18.4/\mathrm{m}^3$. The contractor-based costs were $\$2/\mathrm{m}^3$ higher than the BC Hydro-based costs, making comparisons between non-standardized studies more difficult. Comments on additional elements required for detailed timing are provided.

N. Slewiskin Creek (Walsh 1993)

The excavator push felled an average of 112 trees/h with a range of 42 to 226. It was reported that this depended highly on size of the trees and stand density. Falling time per tree was determined to be 1.2 sec/cm of diameter. The average cycle time for the skidder was 16.5 min, with an average production of 10 pieces/turn. Pushover felling (tree to truck) costs were reported at $\$7342/\mathrm{ha}$ or $\$19.41/\mathrm{m}^3$.

Conclusions are that the studies reviewed are investigative and exploratory in nature, providing initial productivity and cost information on two Armillaria treatment options. The report states that it is not necessary to complete additional time and motion studies with the objectives of updating cost information for the appraisal system; treatment cost information is now being collected by the Valuation Section of the Nelson Forest Region, for determining appraisal allowances for pushover logging and stumping. It is recommended that any future time and motion studies be designed with clear objectives, to address specific operational concerns, such as:

- the effects of different methods of stump management on the productivity of pushover falling, skidding, and bucking phase;
- which phase or phases contribute to differences in productivity of pushover falling versus conventional operations;
- the effects of stumping and pushover falling on subsequent silvicultural regimes (i.e. does the disturbance from pushover falling replace site preparation in some cases, and thus reduce the silvicultural cost?); and
- productivity and other implications of pushover falling in partial cut prescriptions.

The report also stresses the importance of adopting standard elements in future studies to ensure that studies are comparable.

Working Plans/Reports/Publications

De Long, D.L. 1994. Review of five time and motion studies and complete root removal treatments in the Nelson Forest Region. Forest Sciences Section, Nelson Forest Region, BCMOF. Tech. Report TR-006. 20 p.

Maps

None.

Table 6-a. Site descriptions.

	Site			
	Golden-F.D. & Evans	Knappen Creek	Stewart Creek	N. Slewiskin
Region	Nelson	Nelson	Nelson	Nelson
District	Golden	Boundary	Boundary	Arrow
Opening No.		82E048-37	82E009-48	82K012-19
Plot Lat/Long				
Study Area (ha)		50 ha	8 ha	5.1 ha
Biogeoclimatic Subzone/		ICHmk1	ICHdw	ICHmw2
Site Series		04	01	01
Slope (%)		10-40	10-30	30
Aspect				
Species Comp./Age (y) /Site Class		PlLwFd(CwPw)/x/x	LwFdPl(SeHw)/x/x	FdLw(PwCw)/x/x
Stems/ha (no.)		451 (merch.)		592 (merch.)
Terrain/Soil Class./		x/x/SL	x/x/L	x/x/SL
Soil Texture				
Diseases/Insects	DRA	DRA	DRA	DRA
Stand History		logged fall 1989	logged winter 1991	logged winter 1992
Study Establishment	NA	NA	NA	NA
Treatment(s)	Stumping/ Pushover	Stumping	Pushover	Pushover

See Appendix C for abbreviations.

Table 6-b. Summary of trial elements.

Site	Elements					
	Treatment	Methods	Timing elements	Machines	Hours Timed	Costing methods
Knappen Cr.	stumping	detailed timing on 4 ha	Excavator: • stacking slash • stump removal • tree removal • root raking • travel	Cat 227 excavator	1989-8 h 1990-9.5 h	total cost/# of hectares treated
Stewart Cr.	pushover felled (whole trees (stumps and roots attached) were skidded to the landing for processing)	detailed timing & shift level by observation on ≅2.4 ha	Skidder: • skidding and choking • road work • landing work Excavator: • falling • site prep • stump piling • landing function • travel Bucker: • landing • other	JD648D Grapple skidder JD790D Excavator	Skidder: 62 h 49mins Excavator: 65 h 48 min Bucker: 66 h 17 min	total hours of operation x hourly cost figures (BC Hydro rates and contractor rate)
N. Slewiskin Cr.	pushover felled (whole trees [stumps and roots attached] were skidded to the landing for processing)	detailed timing & shift level by observation on 10.6 ha	Skidder: • walk, drag • choke, unchoke • piece count Excavator: • fall, bunch • falling broken down to dig, push, drop • trail • non-merch • walk • fuel, break, other Loader: • logs •debris • loading • breaks, other Bucker: • bucking • sharpen, fuel • break	1 Clark ranger and 1 International S10 line skidder Cat 225/235 Excavator Cat 950 loader	Skidders: 120 h, 39 h Excavator: 97.8 h Loader: 150 h Bucker: 173 h 36 min	total hours of operation for each phase x hourly rates (BC Hydro rates)

SUMMARY 7

Project
EP1186

Partial Cutting in *Armillaria ostoyae* and *Inonotus tomentosus* Infected Stands

Author(s)

D. De Long, J. Pollack, H. Quesnel, and C. Thompson

Study Objectives

1. Demonstrate and compare a clearcut silvicultural system with a shelterwood silvicultural system with two levels of basal area retention.

2. Compare the success of conventional harvesting with pushover harvesting in ameliorating the effects of Armillaria and Tomentosus root diseases on seedling survival and growth, and residual tree performance.

3. Evaluate the establishment and performance of natural and artificial regeneration associated with shelterwood and clearcut silvicultural systems.

4. Investigate the effects of the above silvicultural systems on the seedling micro environment, understory vegetation development, residual overstory growth, coarse woody debris, and soil properties.

Overview

Layout and Treatments

See Table 7-a for site descriptions.

A total of sixteen 1-ha blocks were established at each site. Blocks were laid out to maximize site characteristic homogeneity.

Two replicates of the following eight treatments were randomly assigned in a complete randomized block design (Table 7-b).

Harvesting was undertaken in the winter of 1994/95 (1995/96 for Burton site) with low-ground-pressure harvesting equipment.

Within each 1-ha treatment block a systematic grid (20-m grid spacing) was established for a total of 16 permanently marked subplots. Each sampling grid consisted of three nested plots of radii 1.78, 3.99, and 5.64 m.

In the spring of 1995, Se, Fd, and Lw container stock were planted in all treatment plots at Mt. Seven. Three seedlings of each species were planted within the 3.99-m radius plot. The Burton site was planted with Cw, Fd and Lw in the spring of 1996.

Measurements

Pre- and post-treatment assessments will be conducted in each block and will include measurement of the following variables:

Microclimate/Seedling Physiology

CR10 dataloggers have been installed at Mt. Seven in two control plots, and one replicate of each of the pushover logged treatments. Additional installations depend on the availability of resources. The following parameters are being monitored: precipitation, air temperature, relative humidity, vapour pressure deficit, soil temperature, soil moisture, and solar radiation. Similar datalogger installations will occur at Burton.

Plant growth characteristics of selected tree species will be investigated in relation to environmental variables by monitoring the following phenological stages: prior to bud burst (following snow melt), bud burst 1 (succulent to mature leaf), bud burst 2 (mature leaf to bud set), and bud set to frozen ground. Phenology monitoring will be restricted to the conventionally harvested treatments.

Soils

A post-harvest soil-disturbance survey will be undertaken in all replicates of each of the six harvested treatments. Survey methods will closely follow the grid-point intercept method described in Curran and Thompson (1991).

Growth and Yield

All growth and yield measurements will be centered on the 16-point grid system established in each treatment block. Fixed-area subplots were used in pre-treatment assessments, with the radius chosen so that subplots contained approximately 15 overstory trees. Trees ≥ 4.0-cm dbh were numbered with metal and paper tags in control and treatment areas, respectively, and the following measurements were taken: tree top height for all major species, to a maximum of 10 trees/species/plot; height for 15 trees of major species, in addition to the top height trees; height for 15 trees of minor species; dbh at 1.3 m; FPC crown class; FPC decay indicators; ocular estimate of percent crown closure; and breast height age.

Post-harvest residual trees will be re-tagged and subplot size will be recalculated to accommodate 15 trees per subplot. Subplots in all treatment plots will be re-measured for above variables, as well as 10-year radial increment and height to live crown on trees of all heights. All measurements will be repeated at 5, 10, and 20 years post-harvest.

Regeneration

Pre- and post-harvest assessments of regeneration and germinants will be made in the nested plots. Pre-harvest measurements for Layer 3 stems (>1.3-m high and <7.5-cm dbh) and Layer 4 stems (<1.4-m high and >2-years-old) were taken in the 3.99-m radius plots. Measured parameters included total number of trees; species; average height by species; average age by species; and condition/vigour classified as good, medium, or poor.

Post-harvest, regeneration will be reassessed and monitored for five growing seasons. Germination of all trees ≤2 years old will be monitored post-harvest in the 1.78-m radius plots. Measurements will include number of trees; species; average height; condition/vigour; seedbed, classified as mineral, forest floor, decayed wood, or slash; and ocular estimate of percent cover and vegetation height. Germinants will be monitored for five growing seasons post-harvest. Eight seed traps will be placed in each silvicultural system treatment unit to monitor annual seed rain for a five-year period.

Snags

In each treatment unit, pre- and post-harvest inventories of snags will be undertaken on the 5.64-m radius plots to determine densities and characteristics of snags. Pre-harvest, all living and dead trees ≥4.0-cm dbh were measured, tagged, and assigned to one of three snag classification groups.

Vegetation

Pre-harvest baseline vegetation measurements were undertaken in summer 1994. Herb cover was documented in each quadrant of 1.78-m germination plots using a Daubenmire frame. Average height was estimated for each species, and cover and height values were averaged to obtain a single value for each germination subplot. A modification of the line intercept method was used to measure percent cover and average species height for shrubs. Cover values for herbs and shrubs will be converted to area, and volume will be calculated by multiplying average species height by area. Measurements will be repeated annually for five post-harvest growing seasons.

Woody Debris

Pre- and post-harvest woody debris levels will be inventoried for both sites using the line intersect method (van Wagner 1968). Specific parameters to be measured include: diameter class (for debris <7 cm), diameter (for debris >7 cm), length and orientation, and decay class (classified according to Maser et al. 1979). Woody debris density was measured pre-harvest for some species/diameter/decay classes only. Additional density measurements will be completed if funding is available.

Root Disease

Reconnaissance level surveys were undertaken pre-harvest to determine the homogeneity of Armillaria, cedar Phellinus (Burton), and Tomentosus (Golden) root diseases throughout the study sites. A modification of the line transect method described by Bloomberg et al. (1980) was used.

Post-harvest assessment will be undertaken on the 5.64-m radius plots and will be used to compare above- and below-ground disease incidence (Armillaria only), monitor rate of spread, and monitor survival and growth of planted and naturally regenerated seedlings over time. Seedlings will be monitored every fall from 1995 to 2000, and every third year thereafter for the following variables: height, diameter, Armillaria incidence, and mortality.

Analyses

Microclimate/Seedling Physiology

Regression analysis will be used to investigate the relationships between selected environmental variables and plant growth characteristics.

Soils

Potentially detrimental soil disturbance will be calculated as per Thompson and Curran (1991).

Growth and Yield

Regression techniques using plot means will be used to compare measured variables at different treatment levels.

Regeneration

ANOVAs will be used to compare natural regeneration density and growth, planted regeneration survival and growth, germination rates, and seed rain between treatments.

History/Time Table

1993	Project establishment and baseline assessments.
1994-1995	Harvesting (Golden site).
1995	First growing season post-treatment assessments.
1996-1999	Second to fifth growing season post-treatment assess-

	ments.
2004	10th growing season growth and yield assessment.
2014	20th growing season growth and yield assessment.

Note: Activities at the Burton site will occur in the same sequence, but one year later. No demonstration area is planned for the Burton site.

Status

Ongoing.

Brief Summary of Results

Pre-harvested measurements completed.

Working Plans/Reports/Publications

Crampton, D. 1994. Establishment report for 1993 pre-harvest assessments. Nelson Forest Region, BCMOF.

Crampton, D., G.D. Davis, D.L. De Long, D.J. Morrison, J. Pollack, H.J. Quesnel, and C.F. Thompson. 1993. Partial cutting systems research in the Interior cedar-hemlock zone in *Armillaria ostoyae* infected stands. Working Plan, October 1993. Nelson Forest Region, BCMOF.

Maps

See following.

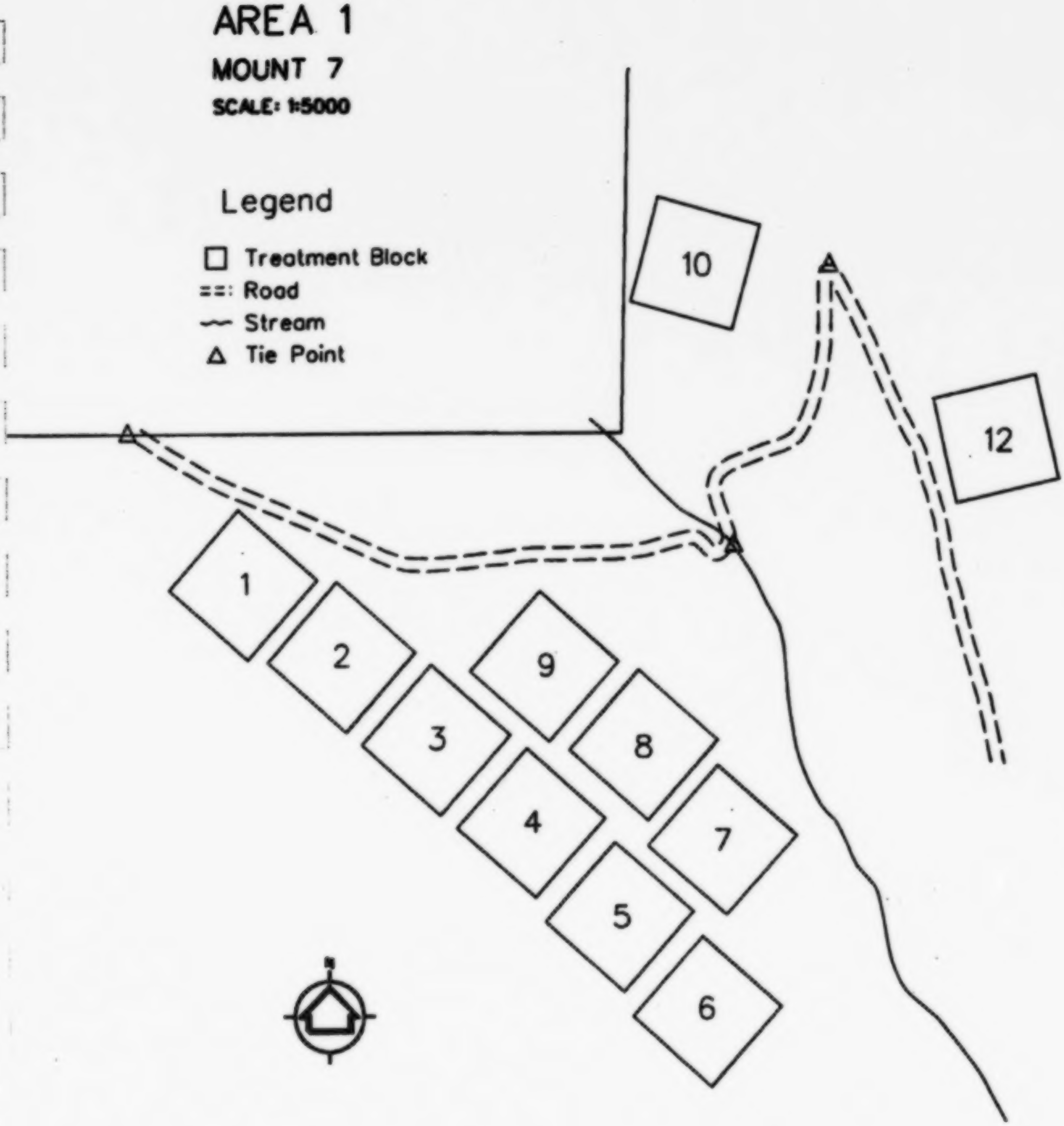
Table 7-a. Site descriptions.

	Site	
	Burton Creek (Ice road)	Mt. Seven
Region	Nelson	Nelson
District	Arrow Lake	Golden
Opening No.	N/A	N/A
Plot Lat/Long	49°58'N 118°43'W	51°17'N 116°56'W
Area (ha)	71.48 (16 - 1-ha trmt units + res.)	70.28 (16 - 1-ha trmt units + res.)
Biogeoclimatic Subzone/ Site Series	ICHmw2 01/04	MSdk/ICHmk1 01/04
Slope (%)	27 - 40	16 - 45
Aspect	N	N
Species Comp./Age (y)/Site Class	OS: $Cw_5Lw_3Fd_2$/90/G	OS: Fd_9S_1/100/G
Stems/ha (no.) (no.)	OS: 750	OS: 650
Terrain/Soil Class./Soil Texture	Colluvium/Moraine/x/L-SiL	Moraine/x/L-SiL
Disease/Insects	DRA	DRT
Stand History	N/A	N/A
Study Establishment	1993	1993
Treatment(s)	1. Clearcut, shelterwood and unharvested control 2. Conventional and pushover logging	1. Clearcut, shelterwood and unharvested control 2. Conventional and pushover logging

See Appendix C for abbreviations.

Table 7-b. Treatments.

Treatment	
Silvicultural system	Harvest method treatment
Clearcut	Conventional logging
	Pushover logging
Shelterwood 1, light retention, approx. 15-m^2 basal area	Conventional logging
	Pushover logging
Shelterwood 2, heavy retention, approx. 25-m^2 basal area	Conventional logging
	Pushover logging
Unharvested control	(For conventional logging)
	(For pushover logging)



AREA 1

MOUNT 7

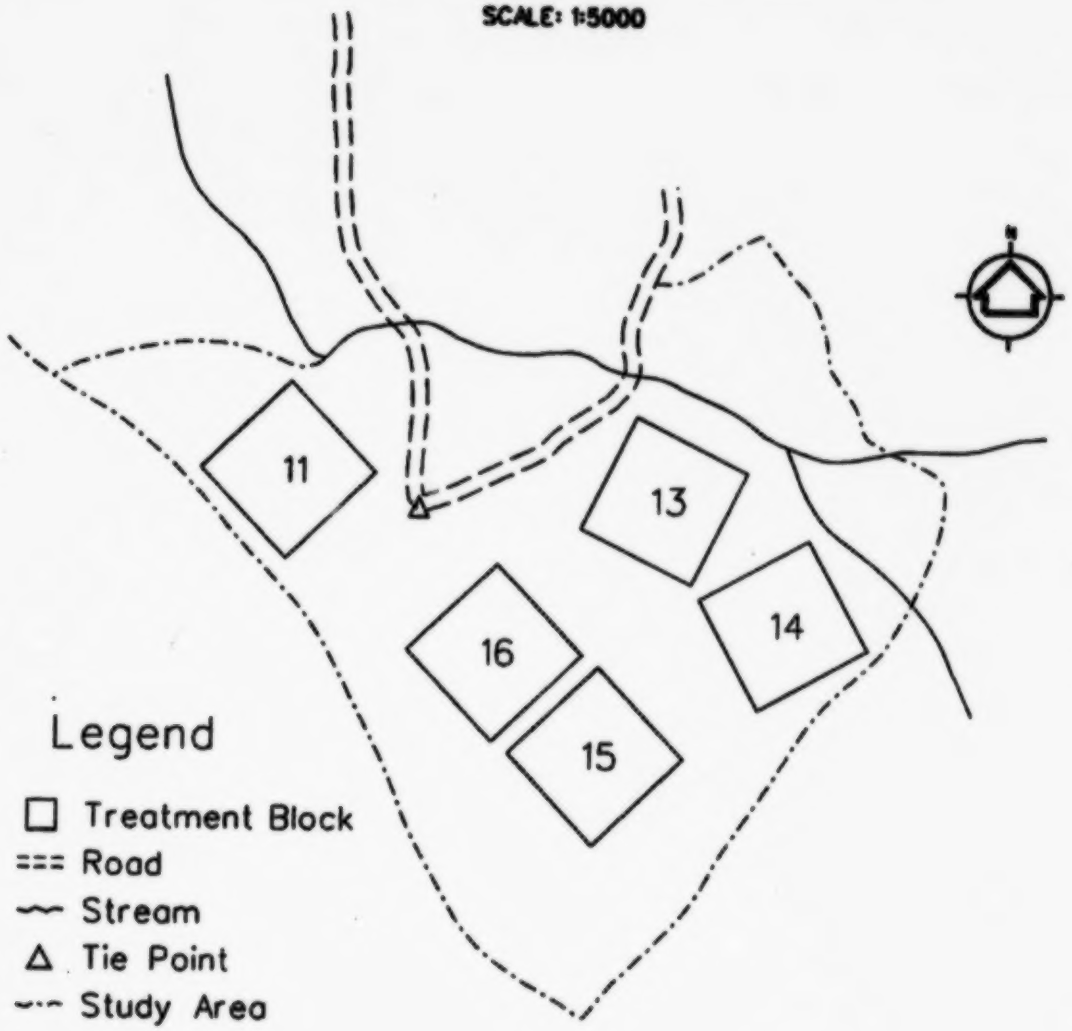
SCALE: 1:5000

Legend
☐ Treatment Block
==: Road
~~ Stream
△ Tie Point
1
2
3
4
5
6
7
8
9
10
12
N

AREA 2

MOUNT 7

SCALE: 1:5000


11
13
14
16
15
Legend
☐ Treatment Block
=== Road
~~ Stream
△ Tie Point
-·- Study Area

AREA 3

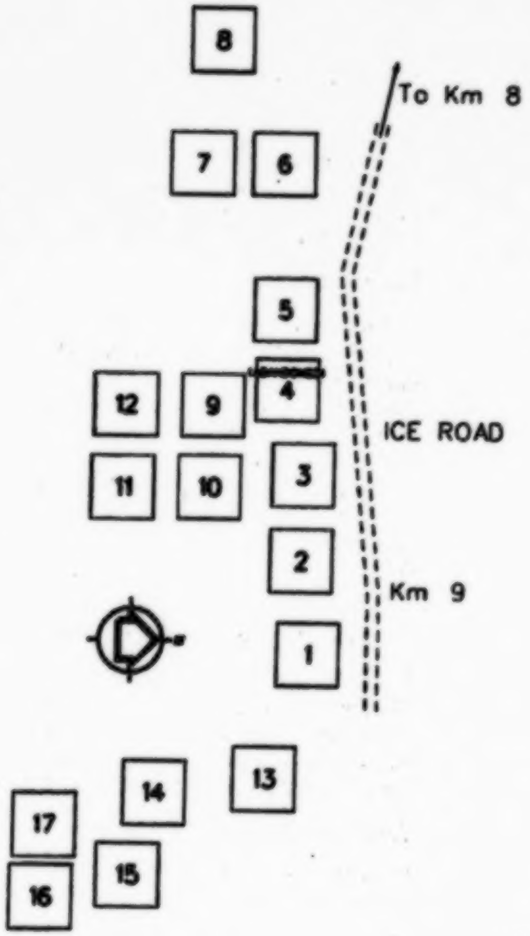
ICE ROAD

SCALE: 1:10000

Legend

☐ Treatment Block

= : Road


8
To Km 8
7
6
5
12
9
4
ICE ROAD
11
10
3
2
Km 9
1
13
14
17
15
16

SUMMARY 8

Project **Galloping Armillaria**

Author(s) D. Doidge

Study Objectives 1. Establish a trial to demonstrate the effect of juvenile spacing on the spread of Armillaria root disease.

Overview

Layout and Treatments

See Table 8-a for site description.

The demonstration trial was established on four blocks previously operationally spaced. In total, thirty-one 10x10-m permanent sample plots were laid out in a 100x100-m grid over the four blocks. The number of plots per block were as follows: 1: 17, 2: 3, 3: 4, and 4: 5. A control area was unavailable.

Measurements

Preliminary Disease Assessment

In each plot, all trees were marked with metal tags. Data collected on each tree included: species and tree disease condition (dead, healthy, presence of Armillaria [e.g. mycelial fans, rhizomorphs]). The condition code did not differentiate between causes of mortality. Western gall rust (*Endocronartium harknessii*) and rodent damage (feeding on resinosis areas surrounding cankers) were not quantified, although they were prevalent on the site. Based on laboratory cultures *Armillaria sinapina*[12]is present on site. No differentiation between *Armillaria ostoyae* and *Armillaria sinapina* was recorded in the field.

Low-level aerial photos (70 mm) were taken of the study plots in 1989; there are no immediate plans for this information.

Follow-Up Assessment

The 1993 follow-up assessment involved a re-evaluation of tree disease condition with respect to the Armillaria incidence. In 1995, re-measurement may include stem mapping, and reassessment of tree condition to include mortality resulting from western gall rust and rodent damage.

Analyses

Descriptive summary statistics were calculated for each tree condition code on a plot and trial basis, and tree mortality rates by block and by year.

History/Time Table

1989	Plot establishment.
1991-1993	Plot re-measurement.
1995	First scheduled re-measurement. And every five years thereafter.

---

[12] *Armillaria sinapina* is a dominant species on the site (D. Morrison, 1996, personal communication).

Status Ongoing.

Brief Summary of Results In the four blocks, mean annual mortality rates (codes dead and infected) in 1989, 1991, and 1993 were 42.5, 31.4, and 41% respectively. Within-year mortality rates among blocks were variable. The mortality rates, for example in 1991, ranged from 53.9 to 15.8%. This variation in part reflects the different sampling intensities between blocks. Interpretations regarding the effect of juvenile spacing on Armillaria spread are limited by the absence of a control block.

Working Plans/Reports/ Publications None.

Maps See following.

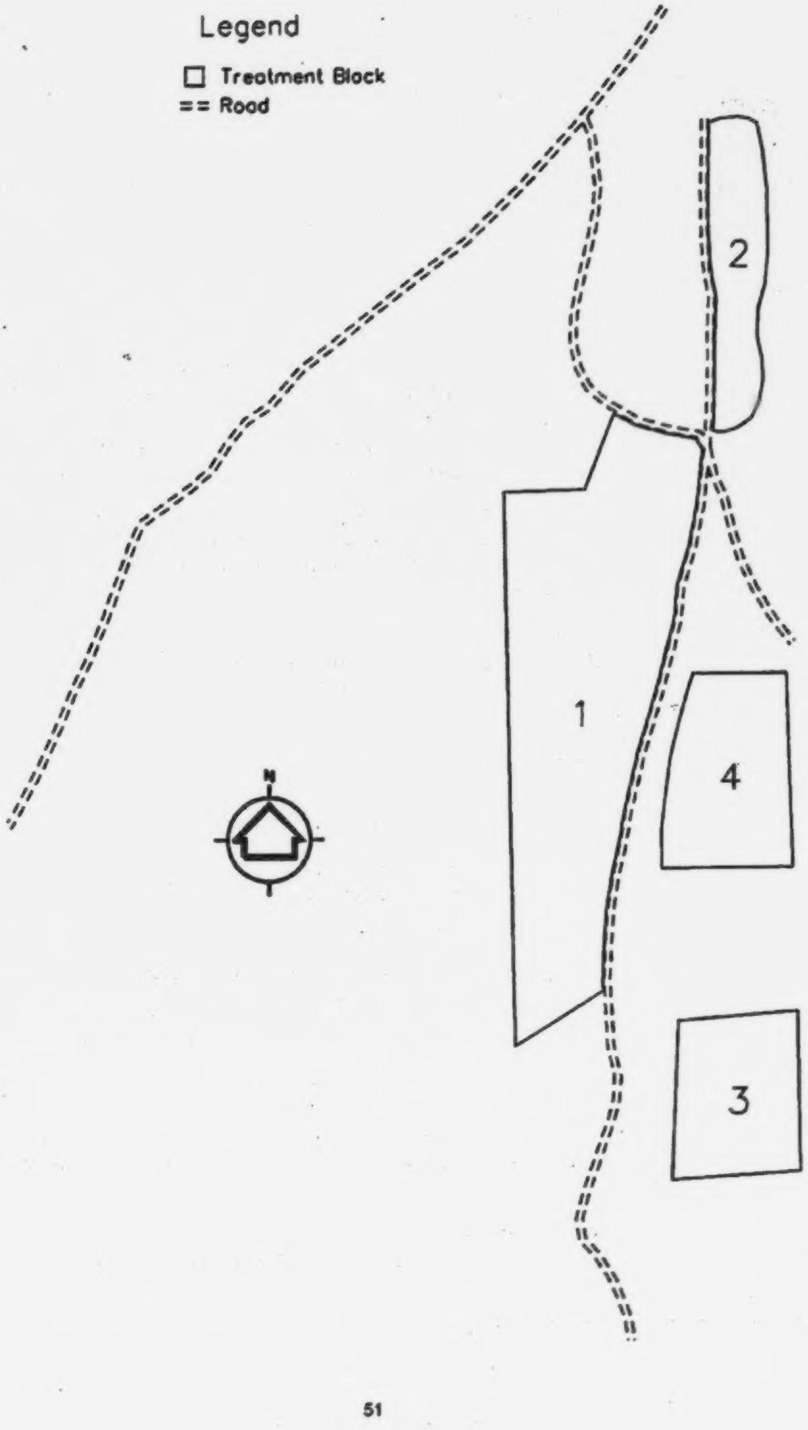
Table 8-a. Site description.

	Site
	Blocks 1, 2, 3, and 4
Region	Cariboo
District	Quesnel
Opening No.	93B/NE Op. 16
Plot Lat/Long	52o44.0'N 122o39.9'W
Area (ha)	20
Biogeoclimatic Subzone/Site Series	SBS dw2/x
Slope (%)	10
Aspect	E
Species Comp./Age/Site Class	Pl/110/G
Stems/ha (no.)	1600
Terrain/Soil Class./Soil Texture	x/x/x
Disease/Insects	DRA, DSG, A
Stand History	logged 1971-1972; juvenile spaced 1987
Study Establishment	1989
Treatment(s)	juvenile spacing

See Appendix C for abbreviations.

Cariboo Region/Quesnel

SCALE: 1:10000


Legend
☐ Treatment Block
== Road
N
1
2
3
4

SUMMARY 9

Project

Pilot Project to Determine the Feasibility of Using Large-Scale Aerial Photography to Detect and Map Armillaria Root Disease in Plantations

Author(s)

K. Edquist, R. Reich, J. Beale, and D. Norris

Study Objective(s)

1. Assess the viability of using large-scale aerial photography in plantations to detect and stratify the location of Armillaria root disease.

Overview

Layout and Treatments

Selection of Study Site

A rotary-wing reconnaissance will be undertaken in selected drainages of the Golden Forest District to identify candidate plantations. Those with a range of visible Armillaria disease expression will be selected for study. Based on numbers of trees with yellow, red, and green crown symptoms, each plantation will be divided into "relative infection" strata (high, medium, low).

Within each stratum, five permanent sample plots (PSPs) will be randomly selected from a numbered grid. Permanent sample plots will be 0.1-ha (30x33.3-m). Each PSP will be located in the field to permit identification in the low-flight photographs.

Low-Flight Photography, 1:5000

Each plantation will be photographed using 12-inch focal length and forward motion compensator. Colour and false colour (colour infra-red) emulsions will be used

Photo Interpretation, 1:5000

Photo interpretation will include:

- triangulate control with TRIM)1:65,000 scale),
- stereo plotting of disease trees (red, yellow, and green) and tree species within each PSP using colour photographs,
- digitizing plantation and strata areas, and
- documenting locations and boundaries of PHSPs.

For each PHSP the number of trees with red, yellow, and green crown symptoms will be tallied and expressed as a percentage of the total.

The usefulness of both infrared photography (1:5,000) and scanning and spectral analysis to identify and define Armillaria root disease signatures based on crown symptoms will also be explored. Two mapping scales will be investigated: planning level (1:20,000), and silvicultural treatment level (1:10,000).

Ground Truthing

Armillaria incidence in each PSP will be ground truthed. All trees within each PSP will be examined for positive identification of Armillaria (i.e. mycelial fans, basal resinosis, rhizomorphs). Armillaria incidence will be expressed as a percentage of the individual crown-based classes (red, yellow, and green) and as a percentage of all trees within the plot.

Measurements

The following parameters will be measured in each plot: species, height, diameter, SI, crown closure, and soil nutrient and moisture regime. Site history will also be documented.

Analyses

Under development.

Reporting and Mapping

The incidence of Armillaria determined in the field will be correlated with the colour-photo-interpreted incidence (red, yellow, and green crowns) to provide an index of bias. The digitized boundaries of the air photo incidence strata will be revised to account for this bias.

The usefulness of both the infrared photography and the spectral analysis will be evaluated separately. A strong correlation between air photo interpretation [colour or infra-red] and field incidence of Armillaria will support the use of low flight photography as a tool for mapping the distribution of Armillaria in plantations. This will permit silviculture treatments to be prescribed on a strata rather than block basis.

History/Time Table

1994-95	Study development.
1995-96	Study initiation.
1996-97	Study completion.

Brief Summary of Results

None available.

Status

Ongoing.

Working Plans/Reports/ Publications

None.

Maps

None.

SUMMARY 10

Project
EP 1172

Stumping for Site Preparation in the Interior Cedar-Hemlock Zone: Effects on Soil Properties and Soil Productivity

Author(s)

G. Hope

Study Objective(s)

1. Determine short- and long-term changes in soil physical and nutrient properties created by different types of stumping operations.

2. Monitor growth and survival of a range of tree species on a range of stumping operations.

3. Evaluate soil disturbance on stumped areas (by using disturbance classes for mechanical site preparation), and relate classes to long-term tree growth.

Overview

Layout and Treatments

See Table 10-a for site descriptions.

Four treatments and two replicates of each treatment at each site will be tested in a fully randomized block design. Treatments include stumping followed by inversion of stumps on site, stumping followed by stump removal off-site, stumping followed by stump removal off-site and forest floor scarification, and control (no stumping).

Treatment plots measure 50x75-m. Each treatment plot is subdivided into three 50x25-m subplots. Subplots are randomly assigned one of three plantings—200 lodgepole pine, 200 paper birch, or 200 Interior spruce—for a total of 600 trees/treatment plot.

Measurements

Post-treatment, soil disturbance surveys will be conducted in all treatment plots. Observed disturbances will be classified according to classes outlined in Curran and Thompson (1991).

Post-treatment assessment of soil nutrients and physical properties in all treatment plots will include measuring of the following variables: bulk density, particle density, aeration porosity, water retention, soil nutrients, and mineralizable N. Seedling performance (height, diameter, condition, mortality) in all treatment plots will be measured in growing years 3, 5, and 10. The presence of root disease (based on above-ground symptoms, i.e. basal resinosis and mycelial fans) will be monitored in all treatments in growing years 5 and 10.

Analyses

Repeated measures ANOVAs will be used to compare measured variables among treatments over time.

Status	Ongoing.	
History/Time Table	1991-92	Adams Lake and Malakwa treated.
	1992	Adams Lake and Malakwa planted.
	1992-93	Soil measurements at Adams Lake and Malakwa.
	1993	Hidden Lake treated.
	1994	Hidden Lake planted.
		Soil measurements at Hidden Lake.
		Seedling growth measurements planned in growing year 3, 5, and 10 at all sites.
	1998	Root disease assessments planned for growing year 5 and 10.
Brief Summary of Results	None available.	
Working Plan/Reports/ Publications	Hope, G. 1994. Establishment report EP 1172. Kamloops Forest Region, BCMOF.	
Maps	None.	

Table 10-a. Site descriptions.

	Site		
	Adams Lake (north end)	Malakwa (5 km E of Malakwa)	Hidden Lake (25 km E of Enderby)
Region	Kamloops	Kamloops	Kamloops
District	Clearwater	Salmon Arm	Vernon
Opening No.	82M043-8315	82L097-056	82L056-21
Plot Lat/Long	x	x	x
Area (ha)	4-5	5	4
Biogeoclimatic Subzone	ICHmw3	ICHmw3	ICHmw2
Site Series	04-05	05 (01)	01
Slope (%)	0	0	0-10
Aspect	N/A	N/A	E
Species Composition/Age(y)/ Site Class	N/A	N/A	N/A
Total Stems per Hectare	N/A	N/A	N/A
Terrain/Soil Class./Soil Texture (% coarse fragments)	GF//X/S	GF/X/S)	M/X/SL
Disease/Insects	DRA	DRA	DRA
Stand History	x	x	x
Plot Establishment	1991	1991	1993
Treatment	Harvested and burned in 1970; stumped 1991/1992: 1. stumped/inverted 2. stumped/removed 3. stumped/removed/ scarified 4. control	Harvested in 1989; stumped 1991/1992: 1. stumped/inverted 2. stumped/removed 3. stumped/removed/ scarified 4. control	Harvested 1979; burned 1980; stumped 1993: 1. stumped/inverted 2. stumped/removed 3. stumped/removed/ scarified 4. control

See Appendix C for abbreviations.

SUMMARY 11

Project

Armillaria Root Disease Impact Analysis for Fir Plantations in the Arrow and Kootenay Lake Forest Districts

Author(s)

K. Hopkins and R. Stewart

Study Objective

1. Investigate the impact of *Armillaria ostoyae* on 16 Douglas-fir plantations in the Interior Cedar Western Hemlock biogeoclimatic zone (ICH) (Arrow and Kootenay Lake TSAs).

Overview

Layout and Treatments

See Table 11-a for site descriptions.

Sites were primarily located in the ICHmw2. Plantation ages ranged between 8 and 16 years.

All Fdi plantations in the ICH biogeoclimatic zone were downloaded from the History Records files. Of these, 32 openings per timber supply area TSA were randomly selected for sampling. Only sixteen of the possible 64 sites were sampled due to time constraints and the lateness of the season.

Measurements

Pixel Surveys: Armillaria infection

The pixel survey traversed the entire opening. In the Arrow District the pixels were established every 25 m along the transect line. In the Kootenay Lake District a less intense survey was undertaken, with pixels established every 50-m along survey transects. In both cases, the presence or absence of *Armillaria ostoyae* was recorded for each 3-m-wide pixel on either side of the transect for all species. Pixel area covered from 1 to 12% of the opening area (see Table 11-a).

Fixed-area plots: proportion of planted versus wild stock infected with *Armillaria ostoyae*

Plots with a 3.99-m radius (1/200 ha) were located equidistant along survey lines, except for the first plot which was assigned one-half this distance. These survey lines were not the transects used in the pixel survey. The maximum number of plots was 30, with the following rules for smaller blocks: 1 plot/ha for blocks 1-9 ha; 15 plots/ha for blocks 10-15 ha; and 30 plots/ha for blocks 16+ ha. The area surveyed ranged from 0.1 to 1.0% of the opening (see Table 11-a).

In each plot, conifers >0.5-m high were tallied by species, origin (planted or wild stock), age class, and health code. Deciduous trees >2-m high were recorded by species only.

Age classes were defined as:

Class 1 = 1 to 5 years
Class 2 = 6 to 10 years
Class 3 = 11 to 15 years

Class 4 = 16 to 20 years
Class 5 = >20 years

Health codes were defined as:

Health Code 0 = Healthy
Health Code 1 = Healthy and within 3 m of infected or killed stem
Health Code 2 = Infected with root disease, i.e. mycelial fans present
Health Code 3 = Mortality due to root disease, i.e. mycelial fans present
Health Code 4 = Health affected by the other agents
Health Code 5 = Mortality due to the other causes

Analyses

Statistical analyses were limited to summary statistics.

Pixel Survey

Percent Armillaria infection was calculated as the infected pixel area divided by the total pixel area surveyed. (A pixel is counted as infected if one or more trees fall within Health Codes 2 or 3.)

Fixed-Area Plots

Data was summarized by age class and health codes. The following totals were calculated by site:

- current annual mortality: equal to the percent of Fdi and wildling stems in health code 2, and
- total infected stems: equal to the percent of Fdi and other stems in Health Codes 1, 2, and 3.

Status

Completed.

History/Time Table

N/A.

Brief Summary of Results

Pixel Surveys

Based on the pixel surveys, the percentage of the planted area with active Armillaria root disease across all 16 sites ranged from 2.7 to 35.7% (mean/SEm: 18.2/2.6). Armillaria root disease was identified at all sites. (The pixel survey results cannot be directly compared to the fixed-area results because the latter includes trees within 3 m of an infected tree (Health Code 1). The inclusion of Health Code 1 will potentially elevate the fixed-area infection values.)

Fixed-Area Plots

The total percentage of Fdi stems infected or challenged (Health Codes 1-3) ranged from 0 to 26% for the 16 sites. Six of the 16 sites had no infected or challenged Fdi stems. For wild stock the total percentage of stems in Health Codes 1 through 3 ranged from 0 to 39.2% for the 16 sites. Six sites had no wild stock stems infected or challenged. Four of the 16 sites had neither Fdi nor wild stock stems infected or challenged.

On a site basis, the current mean annual mortality (% stems in Health Code 2) for Fdi and wild stock ranged from 0 to 8.0% and 0 to 1.3%, respectively. Only six of the 16 sites included Fdi in Health Code 2; only three of the16 sites included wild stock in Health Code 2. When combined, eight of the 16 sites included either Fdi or wild stock stems in Health Code 2.

The weighted current mean annual mortality was reported as 2.3% for Fdi and 0.2% for other species.

The authors concluded that:

- The percentage of stems in Health Codes 1, 2, and 3 is significant, but acknowledge that some of the reduced stocking includes seedling mortality that cannot be separated from the root disease data.
- Wild stock will represent a significant portion of the future stand, and therefore future activity on these sites will have to be carefully planned to ensure a reasonable return on investment; and
- If the current mean annual kill rate of 2.3% for Fdi remains constant, there is the potential for a 1200 stems/ha fir plantation to be reduced to less than 800 stems/ha within 20 years. It was noted that the current annual kill rate will vary from year to year.

Mandatory reporting of pre- and post-harvest Armillaria incidence was recommended.

Working Plan/Reports/Publications

Hopkins K. and R. Stewart. 1992. Root disease impact analysis in fir plantations of the Arrow and Kootenay Lake timber supply areas. BCMOF. Victoria.

Maps

None.

Table 11-a. Site descriptions.

	Site						
	1/Wilson Cr.	2/Wilson Cr.	3/Kuskanax Cr.	4/Fitzstubbs Cr.	5/Little Wilson Lake.	6/Kuskanax Cr.	7/Fish R.
Region	Nelson	Nelson	Nelson	Nelson	Nelson	Nelson	Nelson
District	Arrow	Arrow	Arrow	Arrow	Arrow	Arrow	Arrow
Opening No.	82K003-001	82K003-004	82K022-026	82K023-019	83K023-026	82K032-010	82K092-005
Plot Lat/ Long	117 24'/50 02'	114 24'/50 04'	117 47'/50 16'	117 32'/50 13'	117 34'/50 14'	117 39'/50 18'	117 36'/50 55'
Area (ha)	16	49	148	26	24	24	24
Biogeoclimatic Subzone/Site Series	ICHmw2	ICHmw2	ICHmw2-01	ICHmw2-01	ICHmw2-03	ICHmw2	ICHwk
Slope (%)	25	40	30	20	0	50	15
Aspect	SE	E	SE	SW	flat	S	E
Species Compn.	Fdi$_4$Ep$_3$Hw$_2$Cw$_1$	Hw$_3$Ep$_2$Fdi$_2$	FdiCePlEp	FdCePw	CwAcFdi	FdiCwPw	FdiCwSe
Age (y)	8	8	21	16	18	14	6
Stems/ha (no.) (Fd/Other/Total)	1200/350/1550	1057/2257/3314	550/1906/2456	933/1578/2511	550/1578/2128	1133/720/1853	692/754/1446
Terrain/Soil Class./Soil Texture	x/x/SL	x/x/SL	x/x/S	x/x/SL	x/x/LS	x/x/L	x/x/x
Disease/Insects	DRA	DRA	DRA	DRA	DRA	DRA	DRA
Stand History	P1985	P1985	P1972	P1977	P1975	P1979	P1987
Plot Established	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Treatment	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Pixel: % DRA (area)	11.6	12.5	33.5	20.8	14.0	16.4	2.7
Plot: % DRA (Fdi, Wildlings, Stems/ha (no.))	2.1,0	6.8,12.7	24.8,2.3	26.2,3.5	14.5,4.3	4.7,0	0,0
Pixels (25 mx3 m)	112	112	194	144	150	240	112
Total Pixel Line m	1400	1400	2425	1800	1875	3000	1400
Plots (0.005 ha)	15	14	26	18	20	30	14
Pixel Intensity [a] (%)	5.3	1.7	1.0	4.2	4.7	7.5	3.5
Plot Intensity [b] (%)	0.5	0.1	0.1	0.3	0.4	0.6	0.3

[a] Number of pixels x area/block area x 100.

[b] Number of plots x plot area / block area x 100.

See Appendix C for abbreviations.

Figure 11a, continued. Site descriptions.

	Site								
	1/Kaslo Airport	2/Redfish Cr.	3/Houghton Cr.	4/Kaslo R.	5/Kamma Cr.	6/Bayonne Cr.	7/Harrop	8/Busk Cr.	9/Cold Cr.
Region	Nelson	Nelson	Nelson	Nelson	Nelson	Nelson	Nelson	Nelson	Nelson
District	KL	KL	KL	KL	KL	KL	KL	KL	KL
Opening No.	82F096-023	82F065-035	82F077-063	82K005-002	82F039-026	82F016-050	82F055-001	82F065-044	82G011-023
Plot Lat/Long	50 42 55 268	49 67 55 054	51 54 55 054	49 57 55 387	55 20 54 707	57 070 54 402	49 46 54 939	49 11 549 577	57 85 54 440
Area (ha)	99	11	33	8	34	11	2	2	43
Biogeoclimatic Subzone/ Site Series	ICH dw	ICH dw	ICH dw 01	ICH	ESSF wm2	ESSF wc1	ICH dw 01	ICH mw2	ICHdw 01
Slope (%)	10	38	20	0	15	25	30	25	20
Aspect	N	SW	N	flat	SE	S	N	W	SE
Species Composition									
Age (y)	5	5	6	16	8	8	7	4	19
Stems/ha (no.)	942/1650/2592	238/1225/1463	900/1208/3008	200/1975/2175	47/2053/2100	227/1829/2056	650/2850/3500	950/150/1100	320/2340/2660
Terrain/Soil Texture									
Disease/Insects	DRA	DRA	DRA	DRA	DRA	DRA	DRA	DRA	DRA(6.0)
Stand History	P1988	P1988	P1987	P1977	P1985	P1985	P1986	P1989	P1974
Study Establishment	NA	NA	NA	NA	NA	NA			
Treatment(s)	NA	NA	NA	NA	NA	NA			
Pixel: % DRA (area)	14.8	16.2	20.6	34.2	10.2	10.0	31.3	35.7	6.0
Plot: % DRA (Fdi, Wildlings Stems/ha (no.))	0,6.1	0,1.2	5.9,1.9	25,39.2	14.3,14.9	0,0	0,0	0,0	6.3,1.7
Pixels (25x3m)	188	68	102	38	118	30	16	14	116
Total Pixel Line m	4700	1700	2550	950	2950	750	400	350	2900
Plots (0.005 ha)	24	17	26	8	30	15	4	4	20
Pixel Intensity [a] (%)	2.8	9.3	4.6	7.1	5.2	4.1	12.0	10.5	4.0
Plot Intensity[b] (%)	0.1	0.8	0.4	0.5	0.4	0.7	1.0	1.0	0.2

[a] Number of pixels x area/block area x 100. [b] number of plots x plot area / block area x 100. See Appendix C for abbreviations.

SUMMARY 12

Project
(Pest Control Project JM-101)

Wickman Creek Armillaria Survey Assessment

Author(s)

Kimmur Forestry Consultants Ltd.

Study Objectives

1. Conduct a line intercept survey for Armillaria root disease at Wickman Creek.

2. Compare Armillaria root disease detection using the line intercept method versus a pixel survey of the same area.

3. Compare the results of the two survey methods.

Overview

Layout and Treatments

Site information was not provided in the Pest Control Project JM-1010 summary (BCMOF 1990).

An operational timber cruise, using a 100-m grid, was employed on a 400-ha block infected with Armillaria root disease. In addition to the standard cruise data, information was collected for Armillaria and other damaging agents (dwarf mistletoe and Douglas-fir bark beetle).

Measurements

Pre-Treatment

Armillaria damage was coded per tree as:

Code 0 = No infection
Code 1 = Crown symptoms only
Code 2 = 1% to 50% basal resinosis
Code 3 = 51% to 99% basal resinosis
Code 4 = Recently killed
Code 5 = Old kill

A pixel survey, consisting of 3-m wide by 50-m long pixels (4 pixels/100-m of strip), was performed between plots. Pixels were rated as either infected or healthy based on at least one infected tree or stump per pixel. The line intercept method was used to determine the efficacy of the pixel survey. Further details on the line intersection method were not provided in the Pest Control Project JM-101 summary (BCMOF 1990).

Post-Treatment

N/A.

History/Time Table

Winter 1990 (February - March) Field survey.

Status

Unknown.

Brief Summary of Results

Most Armillaria damage consisted of trees with symptoms (Code 1). A total of 67% of the pixels contained Armillaria root disease versus an infection estimate of 66% for the line intercept method (measuring the length of infection centers). Subsequent observations by the Regional Forest Pathologist suggested that neither method did not overestimated the extent of the disease.[13] The pixel method was found to be 10 to 15% less productive than the line intercept method.

Contractor's Recommendations

- Pushover logging was recommended on the shallower slopes.

BCMOF (1990) Comments

No specific recommendations were made for pixel surveys to determine Armillaria infection levels. No detailed comparison of the methods, as outlined in the contract objectives, was performed. In any event, the pixel survey method would be applicable only in those areas where disease mapping is not needed. Additional evaluation of the two methods would be desirable. Any future assessments should compare lengths of pixel; 30x3-m may be optimal.

Working Plans/Reports/Publications

Patterson, B. 1990. Wickman Creek operational trial - Contract No. PM89N00.05, Minor Services Contract 17558. Contractor's Report. 14 pp.

Maps

None.

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[13] D. Norris, 1990, personal communication.

SUMMARY 13

Project
(Pest Control Project 55 and 56)

Quartz Creek Armillaria Root Disease Survey and Survey for an Armillaria Root Disease Control Trial

Author(s)

Klaus Roethel Forestry Consulting Services

Study Objectives

1. Conduct an Armillaria root disease survey, using the line intercept/Armillaria regeneration survey method, to establish infection levels and obtain data on other site factors.

2. Mark out the boundaries of suitable treatment blocks and produce a detailed map.

3. Survey a plantation near Quartz Creek to determine the suitability of the area for root disease control trials.

4. Conduct an Armillaria/regeneration type survey on a portion of this site.

Overview

Layout and Treatments

Quartz Creek Root Disease Study

A 24-ha site 40 km north of Golden containing overmature western hemlock-spruce-fir-cedar was surveyed. The line intercept/Armillaria regeneration method was employed on a grid of 50x100 m to ensure adequate coverage. Data on Armillaria infection were obtained within plots. Overall infection levels were estimated as 13%. The site was considered to be suitable for a control trial. Six treatment blocks were delineated. Treatments were to include a control and various stumping operations.

Armillaria Root Disease Control Trials

A 20-ha plantation was surveyed near Quartz Creek, 40 km north of Golden. Armillaria infection levels were measured within plots; and suitability of the area for control trials was assessed. The overall infection level was determined to be moderate at about 5%. Block boundaries were laid out for five adjacent treatment units, plus a separate control area.

Measurements

Pre-Treatment

Details on site and survey measures were not provide in the summaries of either Pest Control Project 55 or 56 (BCMOF 1990).

Post-Treatment

N/A.

History/Time Table

October to November 1988. Armillaria surveys.

Status

Unknown.

Brief Summary of Results

Contractor's Recommendations

Quartz Creek

- Conduct stumping on four blocks to reduce inoculum levels while minimizing site compaction.
- Consider stumping with an excavator (backhoe) and pushover logging as alternative treatments.
- Do not employ crawler-tractor stumping because this equipment would create excessive disturbance.

Armillaria Root Disease Trials

No control trial was recommended because disease incidence was only 5%.

BCMOF (1990) Comments

Quartz Creek

The trials are to be conducted on this site in the near future. The survey method was effective for determining the amount of infection. Follow-up activities include studies of stumping and/or pushover logging trials with follow-up monitoring. An evaluation of the performance of similar trials on other sites infected with Armillaria root disease in the Interior, and those infected with laminated root rot on the Coast, should be undertaken.

Armillaria Root Disease

The site should be regularly monitored for disease spread.

Working Plans/Reports/Publications

Roethel, K.E. 1989. Root rot survey at Quartz Creek Control Area. Contractor Report. 4-6 pp.

Maps

None.

SUMMARY 14

Project

Occurrence of Armillaria Species in Site Series of Undisturbed Mature Forests in Subzones of the ICH Biogeoclimatic Zone in the Nelson Forest Region

Author(s)

G. Krumlik, D. Morrison, and R. Nevill

Study Objectives

1. Describe the distribution of Armillaria species in mature undisturbed natural forests in site series of several ICH subzones, and relate this distribution to moisture and nutrient regime.

2. Assess possible roles of different Armillaria species in ecosystem dynamics in the ICH biogeoclimatic zone, such as in tree mortality, regeneration, succession, nutrient cycling, etc.

3. Examine ecosystem niches being occupied by different Armillaria species; where Armillaria species distributed are in association with what other plant species, and how Armillaria species affect ecosystem processes.

Baseline data collected in this project will provide information on the function of Armillaria species in undisturbed ICH ecosystems, and further our understanding of the interaction between the fungus and its hosts. This understanding will contribute to development of less invasive management strategies and perhaps biological control of Armillaria root rot.

Overview

Layout and Treatments [14]

Subzone Selection

Six of the possible eight subzones/variants identified in the Interior Cedar Western Hemlock (ICH) zone will be sampled: ICHxw, ICHdw, ICHmw2, ICHmk1, ICH wk1, and ICH vk1. Three site associations will be sampled in each subzone: xeric, mesic, and hygric.

Site Selection

Sample sites will be established in mature forests (over 80 years old) undisturbed by harvesting.[15] Three replicate sites per subzone will be selected. Sites will be homogeneous with regard to site association and timber type in a 30x30-m area.

Plot Locations

Five sampling locations, 1x1-m (one pedon), will be randomly selected within the sample site. Each sample plot will be selected by taking a random bearing from middle of sampling area and going to the nearest tree. The sample plots will be within 2 m of a trees, shrubs, or herbs desired to be sampled for Armillaria presence. Paxistima is one example of a shrub sampled for Armillaria.

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[14] The final selection of subzones and sites will be made in consultation with Nelson Region and District personnel.

[15] It is essential to study unmanaged forests so that the fungus-host relationship and site indicator plants have not been disturbed.

Measurements

General Field Sampling

At each site, three plots of one square will be excavated to a depth of 20-30 cm. All roots with a diameter larger than 5 mm will be collected and examined for presence of Armillaria infection. Root species, diameter, health status (healthy, lesion, dead, decayed), total length, and length of infected root segments will be determined and recorded.

Rhizomorphs and infected roots will be collected, measured, and cultured to permit Armillaria species determination. Three samples of inoculum from each Armillaria lesion on a root will be used to determine species. Collected Armillaria specimens will be identified in a laboratory using methods described by Harrington and Wingfield (1995) and adapted for BC by Dubetz et al. (1995). Infected roots will be dissected to assess fungal activity, i.e. progressive or callused, and to determine the age of the callus.

Above-ground Armillaria root rot symptoms will be recorded for all trees within the 5.64-m plot. (Details of symptoms not provided.)

Vegetation description and tree mensuration will be conducted in the 5.64-m radius plot (0.01 ha). One soil profile will be described per site. Soil samples for physical and chemical analysis will be obtained from the LFH layers and the B horizon.

Survival of Inoculum

To distinguish between locations where inoculum is not recovered and a location where conditions prevent Armillaria survival, stem segments colonized by each of the Armillaria species recovered in the above procedures will be buried in plots representative of the site series in which the Armillaria species were collected.

After 12 months, survival and growth of the fungus in the segments (e.g. production of rhizomorphs) will be assessed by examining the buried segments.

Analyses

The nature of the project is descriptive. The following analyses are proposed for each objective:

Objective 1: No subzone or site series effect on Armillaria species occurrence

- n-way cross tabulation, PROC FREQ
- ANOVA, or logistic regression
- x variables—subzone, site series, site, plot, interaction, and response. Response variable—proportion of roots affected.

Objectives 2 and 3: No difference in the ability of Armillaria species survival among subzones or within subzone site series

- Two-way ANOVA
- Variables—subzone, site series, interaction, survival of Armillaria species (e.g. number of blocks in which Armillaria species survive)

History/Time Table

1995	Preparation of working plan.
	Assembling of research team.
	Selection of suitable research sites.
	Initiation of site assessment.
1996	Continuation of selecting and assessing sites.
1997	Completion of field site assessment.
	Data analysis.
	Preparation of reports and publications.
	Extension and demonstration.
1998	Completion of reports and publications.

Status

On going.

Brief Summary of Results

Unavailable at this time.

Working Plans/Reports/ Publications

Krumlik, G., D. Morrison, R.J. Nevill, and L. Safranyik. 1995. Occurrence of Armillaria species in site series of unmanaged, mature forests in subzones of the ICH biogeoclimatic zone in the Nelson Forest Region. Research Branch, BCMOF. Victoria. Internal reviewed working plan.

Maps

Unavailable at this time.

SUMMARY 15

Project **Armillaria Root Disease—Mountain Pine Beetle Interaction**

Author(s) G. Krumlik, L. Safranyik, R. Nevill, and D. Morrison

Study Objectives

1. Relate the occurrence of the endemic infestations of mountain pine beetle to site characteristics and infection by *Armillaria ostoyae* of the host lodgepole pine trees in the IDF and ICH biogeoclimatic zones.

2. Determine mountain pine beetle brood production in *Armillaria ostoyae*-infected trees relative to non-infected trees in stands with endemic infestations of the mountain pine beetle.

3. Determine the incidence of *Armillaria ostoyae* infection in stands with endemic mountain pine beetle infestations and in residual trees following the epidemic.

Overview

Layout and Treatments [16]

Stands with endemic mountain pine beetle populations will be chosen in mesic subzones of the ICH and IDF biogeoclimatic zones in the Kamloops and Nelson Forest Regions. A total of three stands will be sampled in each biogeoclimatic zone. Suitable stands will be accessible and contain several "spot" infestations by the mountain pine beetle (other site criteria not provided).

Objective 1

In each stand, ten fixed-radius, circular plots will be randomly established in areas with spot infestations while another ten plots will be randomly established in non-infested areas. At infested spots, ten infested lodgepole pine trees will be randomly chosen for excavation and examination of their root systems for infection by *Armillaria ostoyae*. At non-infested plots, ten lodgepole pine trees will be randomly chosen and examined for infection by *Armillaria ostoyae*.

Objective 2

In the above-mentioned stands, 15 *Armillaria ostoyae*-infected and 15 uninfected naturally infested trees will be selected at random by taking a complete census of infested spots and infested trees within the spots. Trees will be felled and the first 3 m of the stem sectioned at 1 and 2 m to remove two 50-cm long bolts for measures of emergent beetle and attack densities.

Objective 3

Stands will be chosen in mesic subzones of the ICH and IDF biogeoclimatic zones in the Kamloops and Nelson Forest Regions, but will not necessarily be the same sites as for Objectives 1 and 3. A total of three stands will be sampled in each biogeoclimatic zone. In the above stands and ten circular plots, ten trees chosen at random will be established in each stand using the following characteristics:

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[16] Sampling will include naturally attacked healthy and *Armillaria ostoyae*-infected trees, and directed attack on healthy and *Armillaria ostoyae*-infected trees baited with "Standard Mountain Pine Beetle" bait (Phero Tech Inc., Vancouver, BC). Further information on which trees will be baited is unavailable.

- Incipient epidemic - Stands where mountain pine beetle spot infections contain >40 attacked pines.
- Post-epidemic (5 years post epidemic) - Stands where there is not current attack by mountain pine beetle.

Trees from half of the plots will be excavated to document root infection by *Armillaria ostoyae*. Only above-ground measurements will be made on the trees in the unexcavated plots and the plots will be monitored for above-ground symptoms of infection by *Armillaria ostoyae* for the ten-year period of the project.

Measurements

For all objectives the following measurements and observations will be recorded:

- Exact location of plot.
- Description of sample plot, vegetation, soil, tree mensuration, for classification into biogeoclimatic zone, subzone (variant), and site series.
- Above- and below-ground Armillaria root rot symptoms and incidence of mountain pine beetle-attacked trees occurring on lodgepole pine. Infection by *Armillaria ostoyae* will be determined by gross visual symptoms such as reduced shoot growth, foliar chlorosis, and non destructive sampling of the root systems.
- Description of mountain pine beetle attacks in terms of attack density at dbh and attack success. Estimation of attack and brood totals and densities of the mountain pine beetle in individual lodgepole pine trees will be determined from standardized bark samples taken at breast height (Safranyik 1988).

Additional individual tree measurements will include: age, dbh, radial growth (over past five years), presence or absence of attack by mountain pine beetle, density of attack, attack success, number of diseased roots and proportion roots killed by *Armillaria ostoyae* (for excavated trees), stand density (density to the three nearest trees), and species composition (species of three nearest trees).

All sample plots will be assessed annually for three years.

Analyses

Objective 1

- Analysis of variance. Response variables: proportion of the trees infected by Armillaria root disease.
- Infested and uninfested plots will be subjected to a classificatory discriminate analysis. Quantitative variables: proportion of Armillaria infection, biogeoclimatic zone and stand/site factors (e.g. stand density, stand composition, site quality.

Objective 2

- Analysis of variance. Response variables: number of brood adults/m^2 and attacks/ m^2.

Objective 3

- Analysis of variance. Response variables: proportion of trees infected by Armillaria ostoyae.
- Principal component analysis will be used to analyze the relationships among stand and site variables, biogeoclimatic variables, and infestation incidence.
- Linear correlations will be undertaken between severity of tree mortality during outbreaks (% of pine killed) and each of the following variables: stand density, percent pine, average pine dbh, average pine age, and percent *Armillaria ostoyae* infection of pine.
- Stepwise multiple regression analysis will be done to develop a multiple linear regression for predicting percent pine killed as a function of those stand variables that contribute significantly to the reduction of the variation in the independent variables.

History/Time Table

1995	Preparation of working plan.
	Assembling of research team
	Selection of suitable research sites.
	Initiation of site assessment.
1996	Continuation of selecting research sites and assessing sites.
1997	Completion of field site assessment for Objectives 1 and 2.
	Data analysis for Objectives 1 and 2.
	Preparation of reports and publications for Objectives 1 and 2.
	Extension and demonstration.
	Continuation of field assessment for Objective 3.
1998	Completion of reports and publications for Objectives 1 and 2.
	Continuation of field assessment for Objective 3.
1999	Continuation of field assessment for Objective 3.
2000	Completion of preliminary field site assessment for Objective 3.
	Data analysis for Objective 3.
	Preparation of reports and publications for Objective 3.

Status

Ongoing. Completion 2000.

Brief Summary of Results

Unavailable at this time.

Working Plans/Reports/ Publications

Nevill, R.J., G. Krumlik, L. Safranyik, and D. Morrison. 1995. Armillaria root disease - mountain pine beetle interactions. Internal BCMOF reviewed working plan, Research Branch, Victoria, BC.

Maps

Unavailable at this time.

SUMMARY 16

Project
Pest Control Project 34
(BCMOF 1990)

Trial of a Regeneration Survey Modified to Assess Armillaria Root Disease

Author(s)

Laing, McCulloch Forest Management Services

Study Objectives

1. Test the feasibility of collecting Armillaria root disease data in standard regeneration surveys or free-growing assessments.
2. Determine the extent and/or level of the disease in blocks where there was no previous record of disease presence.
3. Determine if correlations exist between Armillaria root disease incidence and ecosystems, site productivity, or other pests.
4. Determine what threshold levels of infection are acceptable.

Overview

Layout and Treatments[17]

A total of 1088 regeneration survey plots were established in 1321 ha (16 openings) in the Golden TSA. Usual regeneration survey procedures were used, with data on Armillaria root disease collected within plots and between plots. Plots were established on a 100-m grid to ensure adequate coverage. Causal agents were determined for all affected trees. Armillaria had not been recorded previously in any opening.

Measurements

Pre-Treatment

N/A.

Post-Treatment

Measures included measures normally recorded in a regeneration survey. Basis for Armillaria calls were not provided in the summary.

History/Time Table

Summer 1987 (August - September) Survey conducted.

Status

Complete.

Brief Summary of Results

Of the 16 sites surveyed, 81% had confirmed or suspected Armillaria. Ten blocks (63%) were confirmed for the disease, and six blocks (38%) had high infection levels, such that reforestation to required stocking standards was very problematic. Infection was also noted in stands adjacent to some of the infected blocks. It was projected that two-thirds of the blocks will be severely damaged by root disease before they attain rotation age.

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[17] Details about how the 16 openings were chosen or how the plots were established were not provided in the summary. Details on measurements were also not provided.

Blackstation root disease was found on Douglas-fir and lodgepole pine. Root cellar weevils and various stem rusts were recorded on lodgepole pine. Frost, rodent damage, and gall aphids were frequently noted. These agents may have exacerbated Armillaria damage.

Armillaria root disease within regeneration plots was readily identified when crown symptoms were present. However, because of the occurrence of non-symptomatic trees, the estimated number of Armillaria-infected trees per plot was less than actual numbers. Recording the disease between plots was possible, but decreased survey productivity by 10% to 15%. Assessment of Armillaria root disease between plots was inaccurate because of brush and non-symptomatic trees. Numbers of trees recorded between plots could not be used for estimates because of missed trees and variations in infection center distances. The cost of incorporating Armillaria data gathering into a standard regeneration survey was found to be negligible.

Contractor's Recommendations

- Armillaria root disease should be noted and mapped only between plots and should not be quantified. Mapping will provide information on disease distribution for treatment purposes. Disease incidence should be estimated only within plots.

- Information on Armillaria root disease should be incorporated into standard regeneration/free growing surveys.

- Stands should not be assessed as free growing if Armillaria root disease levels exceed five contaminated spots/ha or ≥1% of the plots.

- Contaminated growing spots/ha should be used to measure disease levels between plots because this criterion is easily assimilated into the survey and gives a good description of disease intensity.

- Examine each block for residual timber and determine infection levels in these by means of a walk-through.

- Use root disease models to conduct stand development estimates in each block examined.

BCMOF Comments

- Quantitative correlations could not be made between Armillaria and site index or presence of other damaging agents. This objective would probably best be accomplished with additional surveys and the application of root disease modelling.

- The threshold for Armillaria root disease levels needs to be reassessed, based on additional data from surveys over a broader range of ecotypes. Tentatively, this threshold has since been set at 10 infected spots/ha.

- Line intercept estimates and mapping should be dropped from the survey because heavily infected areas should be treated on a per stratum basis rather than selectively.

- Follow-up activities suitable under the FRDA II include:
  a) Additional surveys over a wider range of habitats.
  b) Adding columns for disease incidence on regeneration survey forms.

c) Training workshops at suitable field locations to transfer techniques to regeneration survey crews. Disease identification should be emphasized.

d) Re-assess the sites surveyed in this project for future development of a suitable root disease model.

e) Correlations between Armillaria root disease, other damaging agents, and site factors.

Working Plans/Reports/ Publications

Laing, K. 1987. Armillaria-regeneration survey: Golden TSA. Contractor Report. 13 pp.

Maps

None.

SUMMARY 17

Project **Augmenting the AAC Through Pest Treatment**

Author(s) B. MacKenzie, R. Stewart, and D. Norris

Study Objectives

1. Evaluate whether specific characteristics in the inventory polygon are diagnostic of forest pest incidence.
2. Discuss potential impacts of forest pests on timber productivity.

Overview

Layout/Treatment

Pest Incidence Surveys

Pest incidence surveys were undertaken in five Districts in 1990 (excluding Kootenay Lake and Revelstoke). Inventory polygons were divided into two categories: "suspect" and "non-suspect". Criteria used to identify "suspect" polygons are presented in Table 17-a. Candidate "suspect" polygons were identified on 1:50,000 maps. Of these, 429 were selected for sampling. Polygon selection was non-random, taking into account factors such as accessibility. Information on polygon selection criteria and sample plot establishment (e.g. location, layout) was unavailable.

Several site criteria, not included in the inventory label (e.g. prior selection harvest, slope), were evaluated on site. Only a very small number of "non-suspect" polygons were sampled.

Forest Pests and Forest Productivity

The FIP (Forest Inventory Planning) files for five Districts were used to produce "suspect" and "non-suspect" summary areas by District and biogeoclimatic subzone. The two Districts not included were Cranbrook and Arrow Lake (FIP files unavailable). These overviews were used to extrapolate the pest incidence results to a regional level.

Average "suspect" polygon MAI estimates were summarized by biogeoclimatic subzone. Hypotheses regarding potential growth losses due to forest pests are discussed.

Measurements

Pest Incidence Surveys

Information on plot establishment, sampling method, and site and stand measurements (e.g. height, species, age, pest codes) was unavailable.

Each sampled polygon was coded according to the leading pest. Leading pest incidence was summarized by biogeoclimatic subzone or zone and expressed as: number of polygons by leading pest; percentage of the total polygons sampled in the specific zone or subzone; and area infected (ha).

Forest Pests and Forest Productivity

Three estimates of mean annual increment (MAI:m^3/ha/y) were discussed: FIP Inventory MAI; field determined MAI; and mean MAI report for each biogeoclimatic subzone based on the biogeoclimatic survey plots.

Average "suspect" polygon MAI estimates were summarized by biogeoclimatic subzone.

Analyses

The "suspect" operable land area of each zone or subzone and District was multiplied by the three average MAIs (by biogeoclimatic subzone or zone) to obtain an estimate of annual growth rate in m^3/y. These regional production values were used to discuss hypotheses on potential yield gains in the absence of forest pests. All results are expressed as graphs or tables.

History/Time Table

N/A.

Status

Completed.

Brief Summary of Results

Pest Incidence Surveys

The results from the pest incidence surveys were only briefly discussed. Leading pests were ranked as follows: root diseases >> pest free > bark beetle > other damage such as animals, dwarf mistletoe, other diseases > other insects. Defoliators and mites were not observed.

The following limitations to the surveys were identified:

- non-random sampling of "suspect" polygons;
- no or limited sampling of "non-suspect" polygons;
- no sampling of "suspect" polygons in two Districts;
- absence of "suspect" criteria in the polygon level; and
- limited replication in certain biogeoclimatic subzones.

These limitations precluded an evaluation of whether specific characteristics in the inventory label could be used to identifying polygons with forest pests. Refer to White and Pollard (Summary 41) for further comments.

Forest Health and Forest Productivity

Three approaches were used to calculate an average MAI for the "suspect" polygons by biogeoclimatic subzone. The average MAI estimates increased in the following order for all biogeoclimatic subzones: inventory (FIP) < field data < biogeoclimatic plots (NFR 1984). The statistical significance of the increases was not tested.

The increase in average MAI between the inventory and field measured estimates was attributed to a consistent underestimation of the height class in the FIP file leading to an underestimation of the site class. The differences between field measured and biogeoclimatic sample plot average MAIs were referred to as "gains" in production in the absence of forest pests.[18] Gains were defined as the difference between annual productivity based on the inventory estimate and the biogeoclimatic classification plot estimate.

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[18] Site index values (SI) based on the biogeoclimatic survey data were used as an estimate of SI in disease-free stands within the region (BCMOF 1984). It is noted that: (1) the biogeoclimatic classification plots were not a random subsample of the total population, and (2) while plots were selected to avoid obvious expression of pest incidence, they may not have been "pest free" (T. Braumandl, Ecologist, Nelson Forest Region,

The limitations of extrapolating the "suspect" polygon data to a "regional" level were discussed and included:

- above-mentioned pest incidence survey limitations,[19]
- inclusion of pest-free polygons in "suspect" polygons, and
- absence of inventory data for two Districts.

For these reasons the study results are applicable only to the sites sampled, and the discussion on the regional extent of forests pests and potential yield gains should be interpreted only as hypotheses.

Recommendations from the report are:

- include pest severity ratings in addition to incidence according to the new provincial standards (references not provided);
- adhere to a random sampling design in the future;
- develop "suspect" parameters based on a complete database of stand and pest characteristics;
- ensure equal sample representation by BEC subzone; and
- establish pest-free growth and yield curves.

Working Plans/Reports/Publications

MacKenzie, B. 1991. Augmenting the AAC through pest treatment. Forest Health Program, Nelson Forest Region, BCMOF. 41 pp.

Maps

None.

1995, personal communication). Further, the biogeoclimatic classification mean site index values used were not stratified by site class, and the proportion of each site class included in the average is not reported. Because similar site classes were not compared in the report, i.e. poor (suspect polygons) versus mean of a range of site classes (biogeoclimatic survey data), relative differences in mean MAI are difficult to explain (J. Pollack AAC Mitigation Team Leader, Nelson Forest Region, 1996, personal communication).

[19] See previous Footnote.

Table 17-a. Suspect parameters.

Ecosystem	Suspect parameter
All Zones	Selective logging Deciduous trees in label
IDFg3	All conifers with site class poor (P) or less All types with crown cover class 5 or less
MSa	Larch and lodgepole pine with site class medium (M) or less All other conifers with site class poor (P) or less Lodgepole pine and spruce types with crown class 6 or less All other conifers with crown cover class medium (M) or less
ESSF (a and b)	All conifers with site class poor (P) or less All conifers with crown cover class 5 or less
ESSF (c only)	Spruce, lodgepole pine types with site class medium (M) or less
ICH (all)	Cedar and hemlock types with site class poor (P) or less All other conifers with site class medium (M) or less All conifers with crown cover class 6 or less
All of the above	Slopes approximately 30%

SUMMARY 18

Project **A Cost Benefit Analysis of Root Disease Management Options**

Author(s) B. MacKenzie

Study Objectives 1. Assess the economic effectiveness of root disease management options in the Nelson Forest Region.

Overview

Layout and Treatments

Site description information not provided.

Measurements and Analyses

Cases

The study develops two simulated case studies of root disease management options, one study based on the Skimikin de-stumping trial, and one on the Galloway spacing area. Using estimates of treatment costs and future yields under each management option, net present values of each option were estimated.

Case 1. The first case study deals with a mature stand ready for harvest with a moderate amount of root disease. The three management options considered were:

1. Conventional - Conventionally log current stand immediately followed by planting with a harvest at culmination age. Silviculture treatments include slash burning and planting after the initial harvest.

2. Fallow - Conventionally log and leave the land fallow for 25 years, then plant and harvest at culmination age. Silviculture treatments include slash burning after initial harvest followed by four grass control burns at five-year intervals, followed by screefing and planting at age 25.

3. Pushover - Pushover log the existing stand, then plant and conventionally harvest at culmination age. Silviculture treatments include piling, burning, and planting following the initial harvest.

Case 2. The second simulated case study deals with an immature stand which was recently spaced, is growing poorly, and has high levels of Armillaria. The three management options considered were:

1. Conventional - Leave the stand to grow until culmination age and then harvest.

2. Fertilize and Pushover - Fertilize the stand immediately, then pushover harvest the current stand in 6 years. Replant and harvest at culmination age. Silviculture treatments include immediate fertilization followed by piling and burning and planting after the initial harvest.

3. Pushover Immediately - Pushover log the current stand immediately then plant and harvest at culmination age. Silviculture treatments include

piling and burning and planting following the initial harvest.

Stand Growth Simulations

In the first case study, stand growth under each management option was based on data from Forestry Canada's Skimikin trials. For the Galloway case study, the inventory YIELD program was used to simulate the treated option, while the untreated option was based on a recent cruise of the site. It would have been better to base yield projections on managed stand growth and yield models such as TASS.[20]

Economic Assumptions

The net present values of each management option were estimated using the following economic assumptions:

- real discount rate of 4% per annum;
- real harvest revenue price increase of 1% per annum;
- average harvest revenue of $40/m^3$;
- average conventional harvest costs of $13/m^3$, pushover logging costs of $16/m^3$;
- rotation ages were assumed to take place at the culmination of MAI; and
- silviculture treatment costs of $250/ha for fertilizing, $500/ha for slash burning, $50/ha for grass control burning, $300/ha for screefing, $50/ha for pushover logging stump pile burning, and $700/ha and $650/ha for planting after conventional and pushover logging, respectively.

When pushover logging is used, the study assumed that harvest volumes will be 20% higher than achieved under conventional logging.[21] The added volume was attributed to higher utilization of the tree's lower bole, as was found in the Stewart Creek pushover logging trial of 1990.

History/Time Table

N/A.

Status

Complete.

Brief Summary of Results

Analysis Results

Table 18-a lists the simulated mean annual increment (MAI), net present value (NPV), and benefit cost ratio for each management option for the two case studies. Using the NPV criterion, the treated options are economically superior to the untreated, and the immediate pushover logging option rates the highest.

Interpretation Considerations

- The models used are abstract simplifications of the functional aspects of real management situations. Because all of the options studied are based on the same model, most inaccuracies are common to all and thus do not affect their comparability. The volumes produced or the financial values should not be taken as accurate estimates of true volumes or values to be expected.

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[20] Current growth and yield models are unable to predict future yields for treatments such as pushover logging (J. Pollack, AAC Mitigation Team Leader, Nelson Forest Region, 1996, personal communication). The growth and yield projections used are, at best, very crude estimates.

[21] Based on the personal observations of Don Norris, Pathologist, Nelson Forest Region.

- The harvest cost assumptions appear to reflect only the tree-to-truck phase of logging and ignore other phase costs such as development, overhead, and haul costs. The use of an average per m^3 revenue for wood loaded on the truck removes the haul cost concern; however, the average revenue for wood delivered to the landing will decline with increased haul distance.
- The use of a real per annum revenue increase of 1% will bias the results towards management options with longer rotations.
- The net present values were calculated only at the culmination of MAI (the physical rotation age), which may differ from the age of culmination of the net present value (the economic rotation age).
- Average harvest costs by harvest method were held constant regardless of harvest volume in the simulations. However, average harvest costs will typically fall as harvest volume increases.
- The general application of these results to other locations is questionable given the lack of sensitivity analysis of the results to both the biological (i.e. site index, treatment response, etc.) and economic assumptions. Sensitivity analysis varies each of the simulation's assumptions in turn, holding all other assumptions constant, in order to determine which assumptions have a major impact on the results.

Working Plans/Reports/ Publications

MacKenzie, B. 1991. A cost benefit analysis of root disease management options. Forest Health Program, Nelson Forest Region, BCMOF. Internal Report. 13 p.

Maps

None.

Table 18-a. Analysis results.

	MAI (m^3/year)	NPV (\$)	B/C Ratio
Case 1 - Skimikin			
Conventional	2.92	-272	0.80
Fallow	4.14	-101nn	0.91
Pushover	5.66	1,748	1.51
Case 2 - Galloway			
Conventional	1.29	897	2.13
Fertilize & pushover	3.91	1,552	1.86
Pushover now	4.07	1,731	1.99

See Appendix C for abbreviations.

SUMMARY 19

Project Phoenix Stumping Trial

Author(s) D. Morrison

Study Objectives

1. Determine the effectiveness of stump removal in reducing the incidence of *Armillaria ostoyae*.

2. Evaluate the relative resistance of western larch and Douglas-fir to Armillaria infection.

Overview

Layout and Treatments

See Table 19-a for site description.

A preliminary survey of the study area was used to identify areas of uniform stocking and disease distribution and intensity. Three 2.5-ha areas were selected for treatment. The three blocks were randomly assigned a treatment: control, stumped, and stumped and root raked.

Post-harvest stumping and raking were done with a D8 Caterpillar.

Post harvest, 20x20 m plots (0.04 ha) were laid out over the disease centers within each block. In each block, the 15 plots were randomly assigned to one of three planting regimes: 100% larch; 100% Douglas-fir; 50% larch, 50% Douglas-fir. Inter-tree spacing of PSB 313 was 2 m.

Measurements

Pre-Treatment

Each 2.5-ha block was intensely surveyed and a sketch map prepared showing the location of all disease centers. Disease centers contained infected and recently killed trees and colonized stumps from prior harvesting.

Post-Treatment

Within each 0.04-ha plot, tree condition was assessed every 2 years. The cause of death was recorded for all dead trees (e.g. Armillaria, voles, insects). At age 15, dbh and height were recorded.

Analyses

Preliminary descriptive statistics by treatment and species have been calculated only for cumulative mortality. In the future, descriptive statistics will be calculated for height and dbh.

The study design does not include treatment replication, which limits the use of ANOVA.

History/Time Table

1980	Trial initiated.
1981	Planted.

1983	First assessment.
1993	Assessments undertaken every two years until 1989, after which assessments were undertaken every fourth year.

Status

Ongoing.

Brief Summary of Results

Early Survival and Growth

Early survival and growth was variable across all three treatments. Survival and growth was poor due to shallow soils in parts of the stumped block, and due to competition from grass across the control. In general, seedling roots were slow to emerge from the plugs in all treatment units.

Armillaria-Caused Mortality

Armillaria caused mortality was first recorded in 1983, two years after planting. In the two stumped blocks, dead seedlings were associated with colonized root pieces; in the control block, dead seedlings were associated with stump roots.

After ten years, cumulative morality due to *Armillaria ostoyae* was slightly higher for larch (0.9-4.7%) than for Douglas-fir (2.0-3.5%). This may just reflect the fact that larch has a greater chance of contracting Armillaria inoculum because it grows faster than Douglas-fir. Treatment differences in cumulative tree mortality by *Armillaria ostoyae* were relatively comparable after ten years. Total cumulative mortality was 7.4 for the control, 7.5 for the stumped treatment, and 5.9% for the stumped and raked treatment.

Total cumulative mortality due to other causes (e.g. insects, breakage, animal [deer, voles], drought and competition [grass] was noticeably higher than Armillaria-caused mortality for all three treatments (ranging from 14.2 to 30.1%).

Working Plans/Reports/ Publications

Morrison, D. 1993. "Phoenix Armillaria Trial" in A Workshop on Armillaria and Integrated Resources Management, Grand Forks, BC August 24, 1993. Armillaria Research Working Group, Nelson Forest Region, BCMOF.

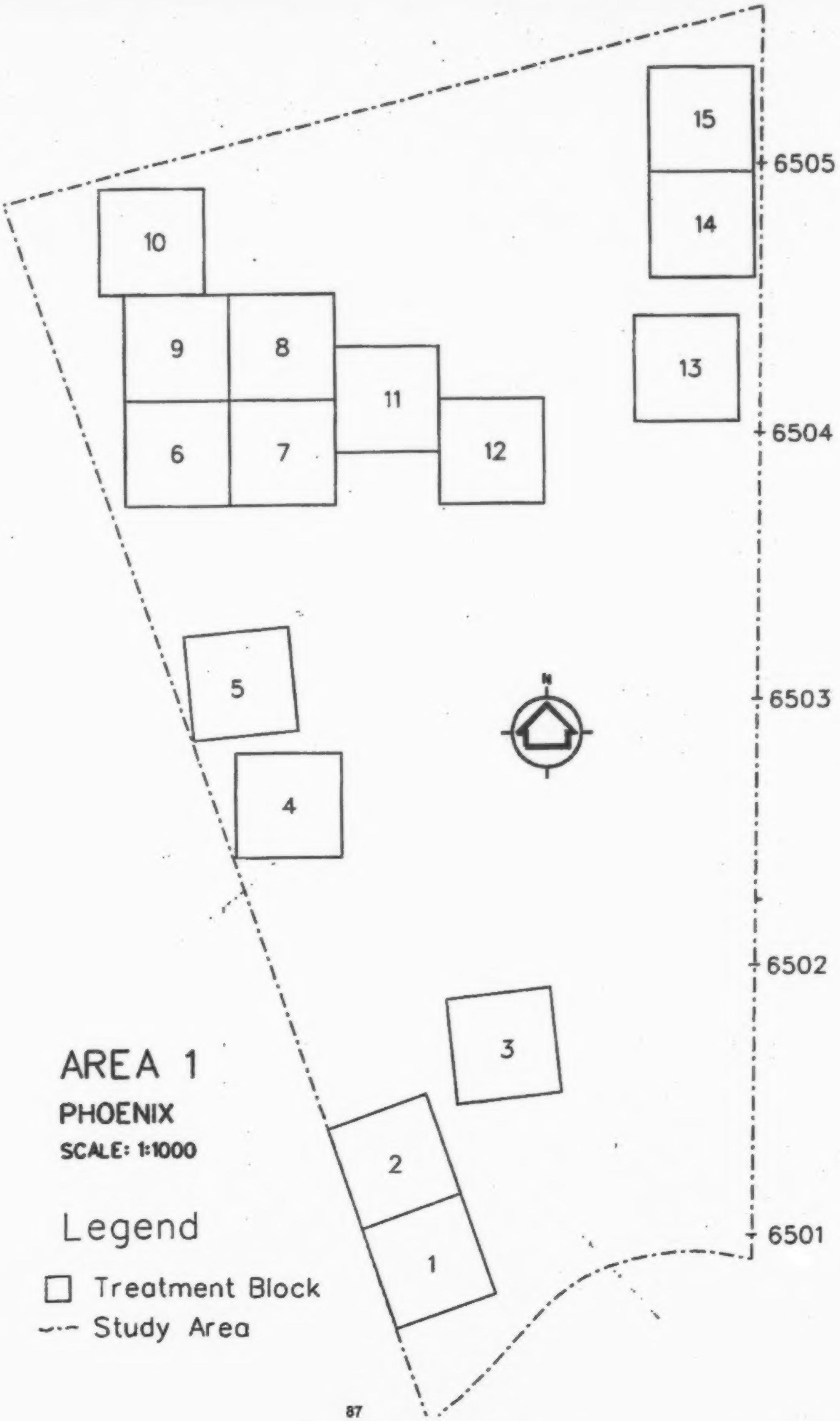
Maps

See following.

Table 19-a. Site description.

	Site
	Phoenix
Region	Nelson
District	Boundary
Opening No.	N/A
Plot Lat/Long	49° 05'N 118° 37'W
Area (ha)	7.5
Biogeoclimatic Subzone	ICH mk1
Site Series	submesic-mesic
Slope (%)	5%
Aspect	S
Species Composition/ Age(y)/ Site Class	OS: Fd,Lw,Pl,Bl/x/x PL: x/x/x
Total Stems/ha (no.)	OS: x/x/x PL: 100/plot
Terrain/Soil Class./ Soil Texture (% coarse frag.)	glacial till/ eluviated dystric brunisol/ silt loam (25)
Diseases/Insects	DRA
Stand History	diameter limit cut three times since the early '50's; logged 1980; planted 1982
Study Establishment	1980
Treatment	1. stump removal 2. larch and Douglas-fir species trial

See Appendix C for abbreviations.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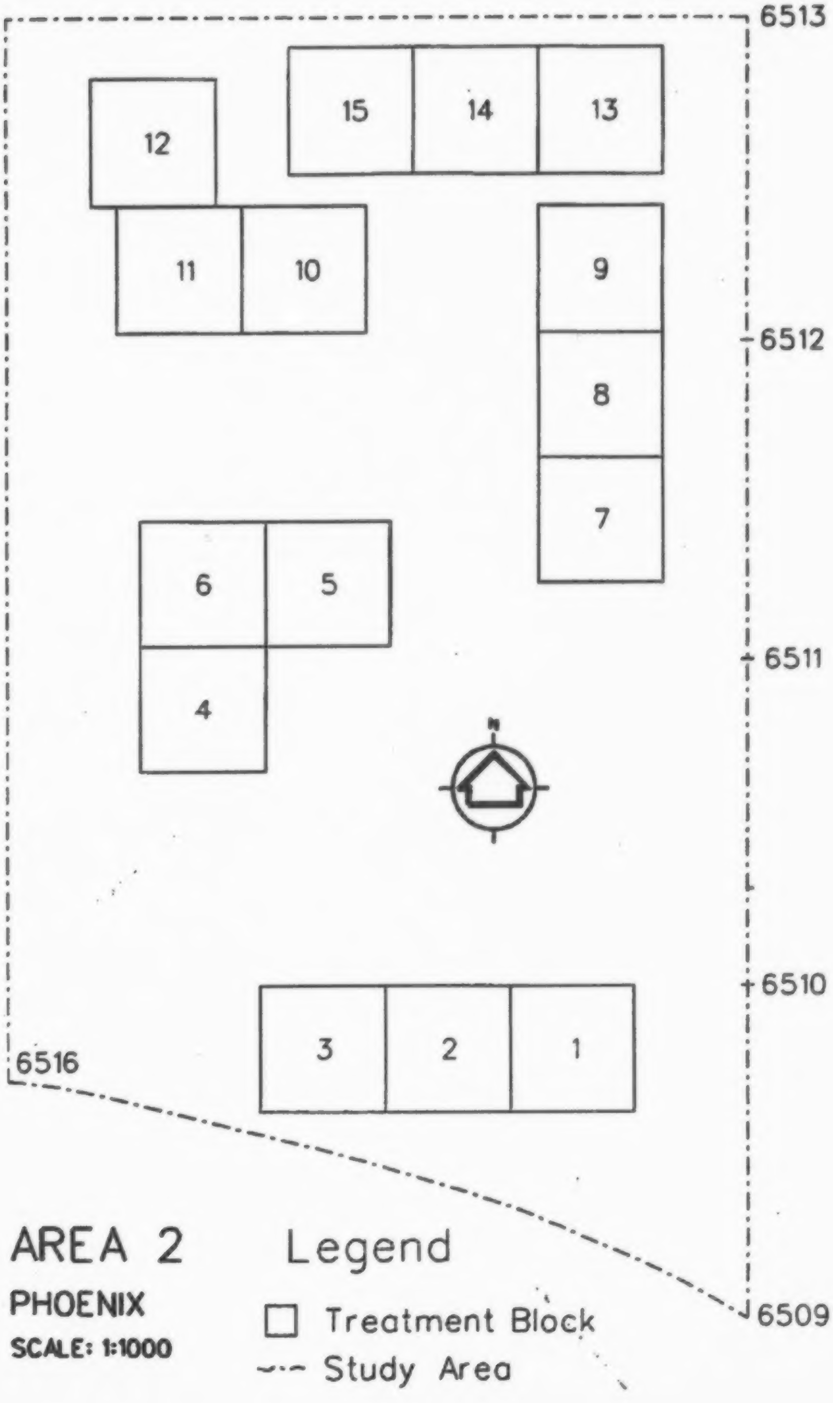
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AREA 2

PHOENIX

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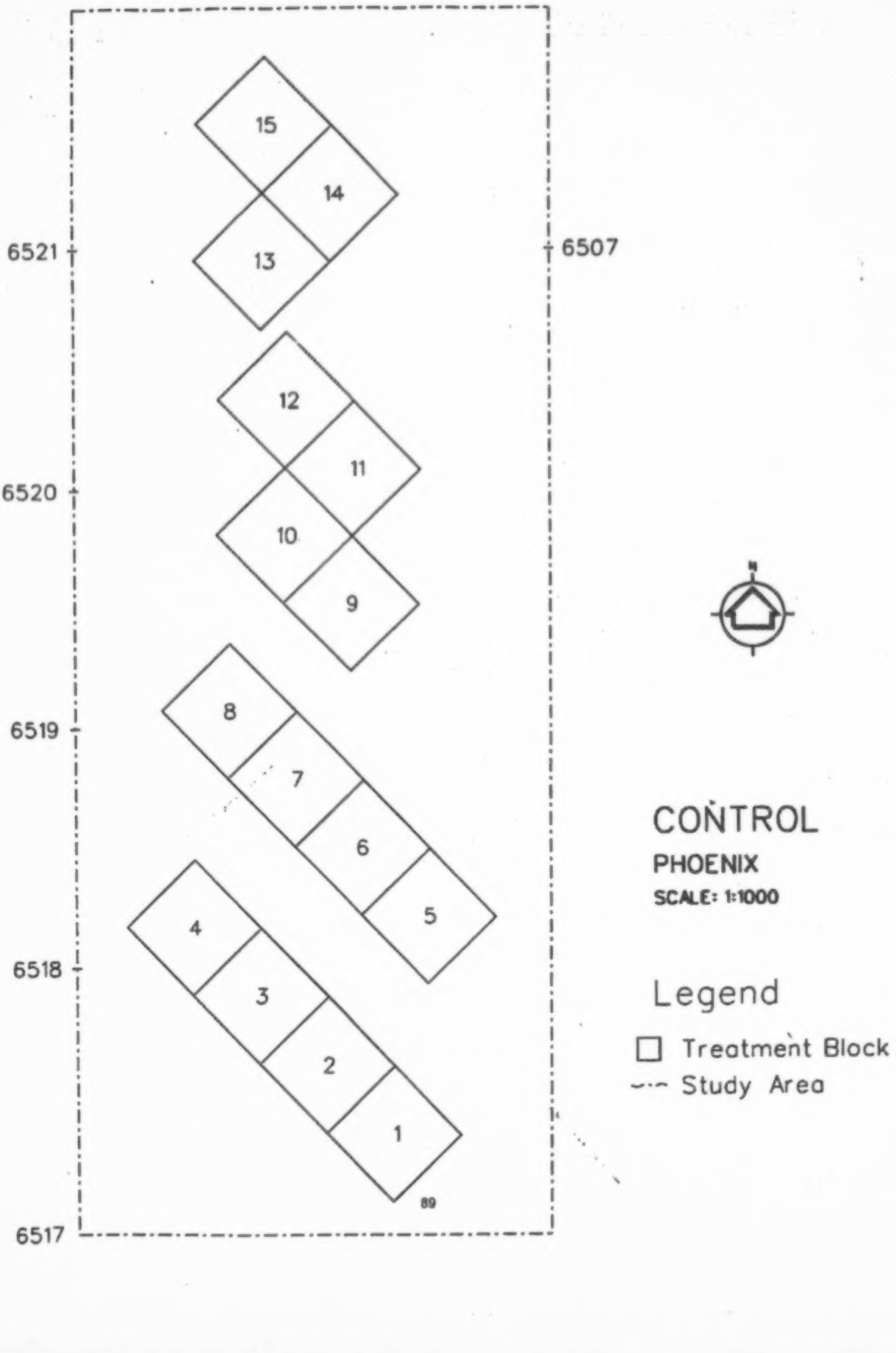
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Legend
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-·- Study Area

SUMMARY 20

Project
SS 008

Effects of Partial Cutting on Armillaria Root Disease in the IDF, MS, ICH, and ESSF

Author(s)

D. Morrison

Study Objectives

1. Document the above- and below-ground incidence of *Armillaria ostoyae*-diseased trees in undisturbed and selection harvested areas.

2. Evaluate the response of *Armillaria ostoyae* (i.e. incidence and distribution) to selection harvesting in stands in the IDF, ICH, and ESSF biogeoclimatic zones by documenting:

- disease severity based on stump and root inoculum
- disease incidence, and
- distribution of symptomatic and dead trees.

Overview

Layout and Treatments

See Table 20-a for site descriptions.

Site selection was based on uniformity of site and stand conditions, and presence of Armillaria. At each site, five 20x20-m plots (0.04 ha) were laid out in each of the undisturbed and selection harvested areas. All plots were conventionally harvested and stumped using an excavator.

Measurements

Prior to harvest, all trees >1.3 m high were tagged and the following information was collected: species, dbh (at 1.3 m), x and y co-ordinates, condition (healthy, infected, dead), disease symptoms[22] (i.e. basal resinosis, mycelium), and root disease identity. The locations of old stumps were also stem mapped (x, y co-ordinates). Current and/or historical presence of Armillaria on old stumps was noted based on viable mycelium and/or mycelial fan impressions in the inner bark.

Post-stumping root measurements included: azimuth and diameter, and length for primary, secondary, and occasionally tertiary roots. The locations of disease on roots were also recorded.

Analyses

Stem maps were generated showing old stumps, and healthy, dead, and infected trees. Infected trees were coded for above- and below-ground disease incidence, permitting a visual qualitative assessment of disease distribution.

Summary statistics were calculated for the following parameters by site and by undisturbed and selection harvested strata (in progress):

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[22] As per: J. Beal, G. Davis, D. Morrison, and J. Pollack. 1994. Recommended standards for establishing and monitoring root disease permanent sample plots. Draft internal document. Nelson Forest Region. BCMOF.

- species composition, age, and diameter distribution;
- above- versus below-ground incidence;
- area and location of root infections (i.e. 1°, 2°, 3° roots); and
- type of host reaction (e.g. no reaction, callus types).

Further data analysis will be undertaken upon completion of data collection.

History/Time Table

1991-92	Madius Creek: harvested, stumped, field sampling completed.
1992-93	Bird Creek: harvested, stumped.
1994	Bird Creek: field sampling completed.
1994	Green Mountain: harvested, stumped, preliminary field sampling.
1995	Green Mountain: field work completed.
1996	MS site boundary District.

Status

Ongoing.

Brief Summary of Results

IDF: Madius Creek

Mortality

In undisturbed plots 1.5% of trees had been killed by Armillaria root disease, and 20.9% in the partially cut plots.

Below-Ground Disease Incidence. In the undisturbed and selection harvested plots respectively, 10 and 44% of trees were infected with *Armillaria ostoyae*. Thirty-four years after cutting, many of the old stumps in the selection harvested plots contained viable *Armillaria ostoyae* mycelium or had decayed wood typical of the fungus.

Above- versus Below-Ground Detection of Diseased Trees. In the undisturbed and selection harvested plots respectively, 27 and 63% of diseased trees were detected based on above-ground symptoms, i.e. readily recognizable disease symptoms on the lower bole or root collar. The root disease was very active[23] in the selection harvested plots. Groups of dead trees were usually associated with old stumps.

Spatial Distribution of Diseased Trees in Plots (based on stump and root symptoms). In the undisturbed plots, diseased trees occurred singly or in small groups scattered over the plots. Large groups of diseased trees, many of which were dead, were found throughout most selection harvested plots. Groups of dead trees were usually associated with old stumps.

ICH: Bird Creek

Mortality

In the undisturbed plots, 10.2% of trees had been killed by *Armillaria os-*

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[23] "active" = high level of recent mortality.

toyae, whereas, in the section harvested plots, mortality was 14.3%.

Below-Ground Disease Incidence. Eighty-one and 91% of trees in the undisturbed and selection harvested plots, respectively, were infected with *Armillaria ostoyae*. This difference reflected a lower incidence of Armillaria in, and greater number of, trees with diameters less than 20 cm in the undisturbed plots. In the selection harvested plots, all old stumps were partially or completely colonized by Armillaria.

In the undisturbed plots, approximately 30% of living tree primary roots were infected, and 45% were infected in selection harvested plots.

Above- versus Below-Ground Detection of Diseased Trees. In the undisturbed plots, only 14.5% of trees with Armillaria lesions on their root systems showed readily recognizable disease signs or symptoms on the lower bole or root collar. A slightly higher percentage, 19.9%, had above-ground symptoms in the selection harvested plots.

After trees were felled, a high proportion of cedar stumps in both treatments were found to have lesions with mycelial fans on the lower bole. In retrospect, the lower boles of the diseased trees are often eccentric, due to the effects of the lesions on stem growth. In mature stands with a cedar understory, disease incidence can be more accurately estimated by careful examination of the lower bole of the cedars.

Spatial Distribution of Diseased Trees in Plots (based on below-ground symptoms). The percent incidence of Armillaria is very high and comparable in the undisturbed and selection harvested plots. No distribution patterns were apparent.

ESSF: Green Mountain

Data collection in progress.

Working Plans/Reports/Publications

CFS File Reports: Silviculture Systems Project 008, Effects of partial cutting on incidence of Armillaria root disease: Working Plan and Progress Reports.

Maps

None.

Table 20-a. Site descriptions.

	Site					
	Madius Creek, partial cut	Madius Creek, undisturbed	Bird Creek, partial cut	Bird Creek, undisturbed	Green Mt., partial cut	Green Mt., undisturbed
Region	Nelson	Nelson	Nelson	Nelson	Nelson	Nelson
District	Invermere	Invermere	Kootenay L.	Kootenay L.	Arrow	Arrow
Opening No.	82J03 1/430	82H03 1/430	82F043 #4	82F043	82L009/ Comp.268	82L009/ Comp.268
Plot Lat/Long	50°25'/115°52'	50°25'/115°52'	49° 26'/117° 25'	49° 26'/117° 25'	50°03'/118°16'	50°03'/118°16'
Area (ha)			192			
Biogeoclimatic Subzone	IDF dm2	IDF dm2	ICH mw2	ICH mw2	ESSF wc1	ESSF wc1
Site Series	mesic	mesic	submesic	submesic	01-02	01-02
Slope (%)	5	5	5	5	flat	flat
Aspect	W	W	NW	NW	none	none
Species Composition/Age(y)/ Site Class	PL: Fdi$_9$Pl$_1$/ 20-0(>50)/M	PL: Fdi$_9$Pl$_1$/ 60-120/M	PL: (LwSePl)/ 80-100/M	PL: FdCwHw (LwSePl)/ 80-100/M	PL: BlSe/20-220/x	PL: BaSe/ 20-220/x
Total stems/ha	PL: 2300	PL: 1600	PL: 760	PL: 1600	PL: 3300	PL: 1900
Terrain/Soil Class/ Soil Texture	x/x/x	x/x/x	x/x/SiL	x/x/SiL	x/x/x	x/x/x
Diseases/Insects	DRA(IBM)	(DRA, IBM)	DRA, IBD	DRA, DML	DRA, DRT	DRA, DRT
Stand History	Natural/ Selection Harvest '58-1962	Natural	Natural/ Selection Harvest 1979-1980 (Pw & Fdi removed)	Natural	Natural/ Selection Harvest 1972-1974	Natural
Study Establishment	N/A	N/A	N/A	N/A	N/A	N/A
Treatment	Harvested & Stumped 1991	Harvested & Stumped 1991	Harvested & Stumped 1992	Harvested & Stumped 1992	Harvested & Stumped 1994	Harvested & Stumped 1994

See Appendix C for abbreviations.

SUMMARY 21

Project
FRDA Project FC-FP-003 [24]

Effects of Pre-Commercial Thinning on Root Disease Mortality by Armillaria

Author(s)

D. Morrison

Study Objectives

1. Determine the effect of pre-commercial thinning on infection and mortality of crop trees by *Armillaria ostoyae*.

Overview

Layout and Treatments

See Table 21-a for site descriptions.

Candidate stands were: well-stocked and of spacing age (preferably 15-20 years), and included trees attacked by *Armillaria ostoyae*. A preliminary survey of candidate stands was used to identify areas of uniform stocking and disease incidence. A 3-ha area was then intensely surveyed and a sketch map prepared showing the location of all disease centers. Disease centers were numbered and ten were randomly selected for study.

At each installation a total of five 20x20-m plots (0.04 ha) per treatment were laid out over the randomly chosen disease centers. A 5-m wide buffer surrounded each plot. Thinning and no thinning treatments were randomly assigned to the total number of plots per site.

Measurements

Prior to treatment, crop trees were selected and tagged within each plot, and dbh and x and y co-ordinates recorded. In the buffer, crop trees were marked but not tagged. Crop trees were identified based on operational juvenile spacing specifications.

In the thinned plots (crop trees) and control plots (equivalent crop trees), trees >1.3-m high were tagged and the following information recorded: species, dbh, and x and y coordinates. The locations (x, y) of Armillaria root disease centers were recorded.

Analyses

Stem maps were generated that located crop trees and disease centers. Infected trees were coded for above- and below-ground disease incidence. Descriptive statistics by site, treatment, and species will include: infection and mortality among crop trees; and distribution of diseased trees.

History/Time Table

Assessed for Armillaria symptoms every two years.

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[24] FRDA Project FC-FP-003 also includes pre-commercial thinning trials for Tomentosus and Phellinus.

Status	Ongoing.
Brief Summary of Results	None to date.
Working Plan/Reports/ Publications	Morrison, D. 1991/92. Effects of pre-commercial thinning (spacing) on crop tree infection and mortality by root disease. CFS Working Plan and Progress Reports.
Maps	See following.

Table 21-a. Site descriptions.

	Site and installation no.							
	Young Lake. / 2	Mag Fire / 7	Kidd Cr. / 4	Lussier / 5	Fitzstubbs / 11	Hornet Cr. / 3	Nusatsum / 8	Talchako / 10
Region	Cariboo	Kamloops	Nelson	Nelson	Nelson	Vancouver	Vancouver	Vancouver
District	100 Mile H.	Salmon Arm	Kootenay Lake.	Invermere	Arrow	Chilliwack	Mid-Coast	Mid-Coast
Opening No.	92P026-30	82MO15-44	82F020-759	82J002-	82K023-024	92H061-25	93D8D10-38	Duncan
Plot Lat/Long	51°18'N/121°02' W	51 07 N/119 03 W	49 15 N/116 08 W	50 05 N/115 40 W	50 14 N/117 35 W	49 38 N/121 50 W	52 22 N/126 28 W	52 20 N/126 03 W
Study Area (ha)								
Biogeoclimatic Subzone/ Site Series	IDF dk	ICH mw3	ICH mw1 01/04	MSdk 01/04	ICH mw2 01	CWH ds1	CWH mm2	CWH ds
Slope (%)	0	0-15	5-10	0	0-10	0-15	10-50	0
Aspect	Flat	E	N		SW	W	E	Flat
Species Composition/ Age/ Site Class	PL: Fdi$_1$(Pl)/ x/x	PL: Fdi$_1$(Hw)/ x/x	PL: BgBl(Hw)/ x/G	PL: Pl$_1$/ x/x	PL: Fd$_5$Cw$_3$Hw$_2$/ x/x	PL: Fd(Hw)/ x/x	PL: Hw(Ba)/ x/x	PL: Fd/ x/x
Total Stems/ha (no.)	PL: x	PL: x	OS: 8000 PL: x	PL: x	PL: x	PL: x	PL: x	PL: x
Terrain/Soil Class./Soil Texture								
Diseases/Insects	DRA	DRA(DRL)	DRA	DRA	DRA, DFR	DRA	DRA	DRA
Stand History	natural	natural	natural	natural	planted 1975	planted	natural	planted 1973
Study Establishment	1991	1992	1992	1992	1994	1991	1993	1993
Treatment	conventional PCT control	conventional PCT control	conventional PCT control	conventional PCT control	conventional PCT pop-up PCT fill in with Lw* control	conventional PCT control	conventional PCT control	conventional PCT control

* Large disease centers fill planted with Lw seedlings.

See Appendix C for abbreviations.

YOUNG LAKE

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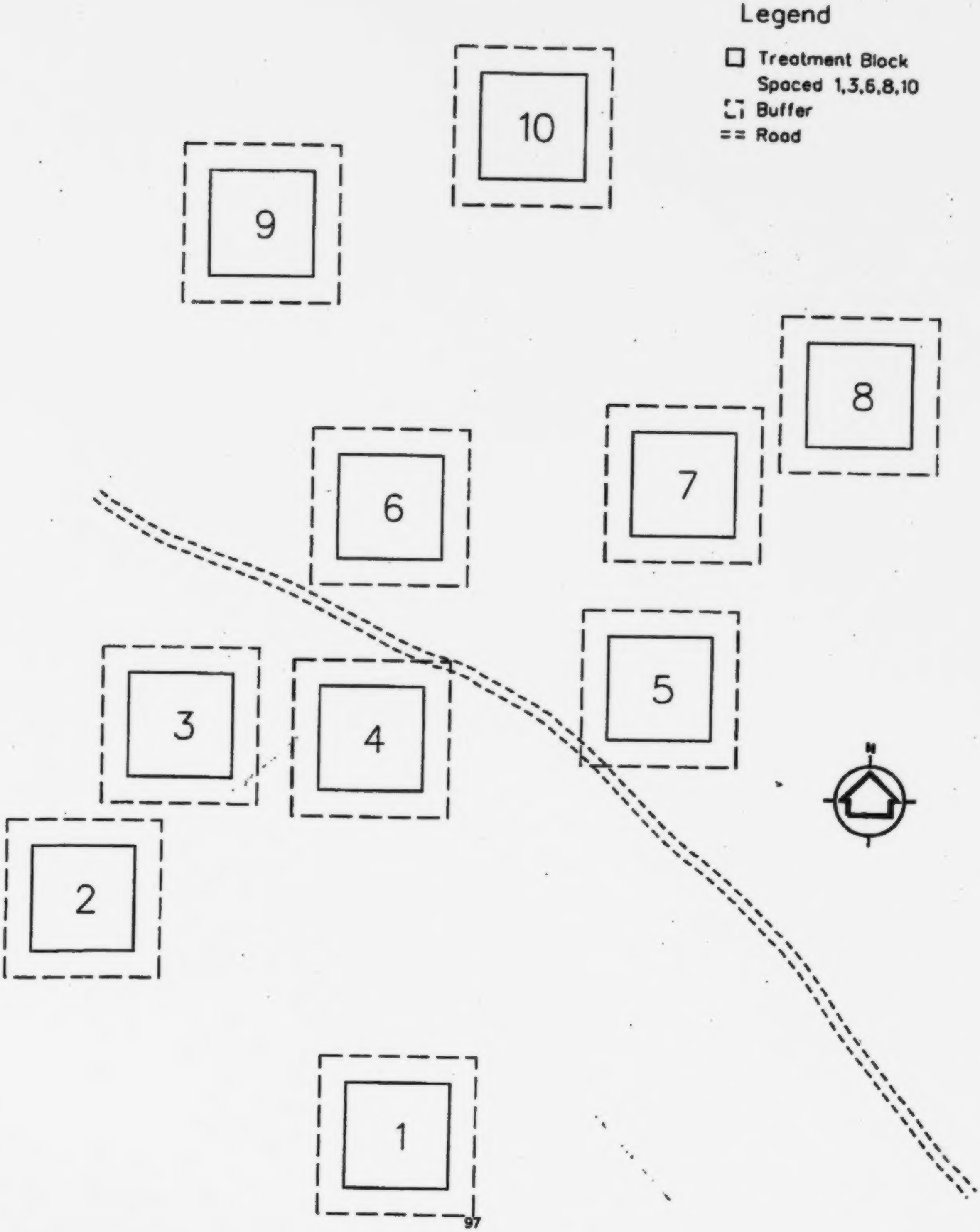
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Treatment Block
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MAG CREEK

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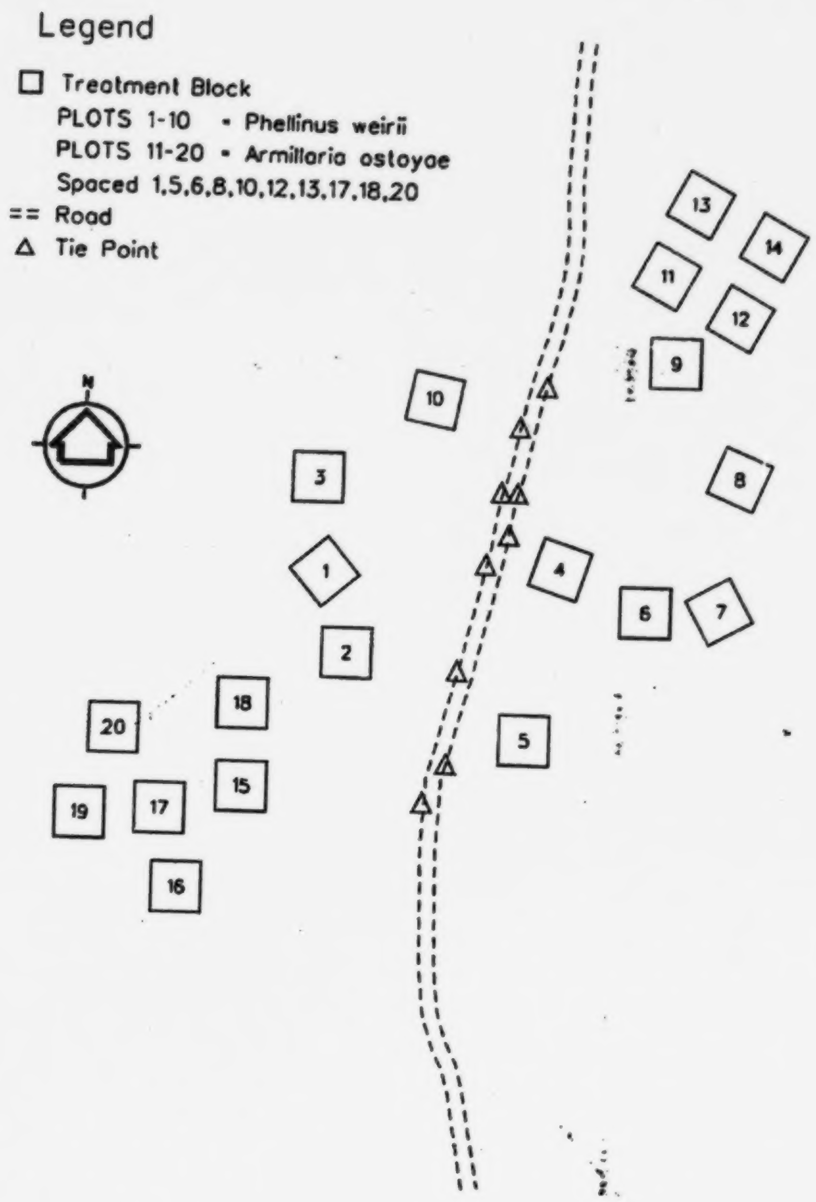
Legend
☐ Treatment Block
PLOTS 1-10 - *Phellinus weirii*
PLOTS 11-20 - *Armillaria ostoyae*
Spaced 1,5,6,8,10,12,13,17,18,20
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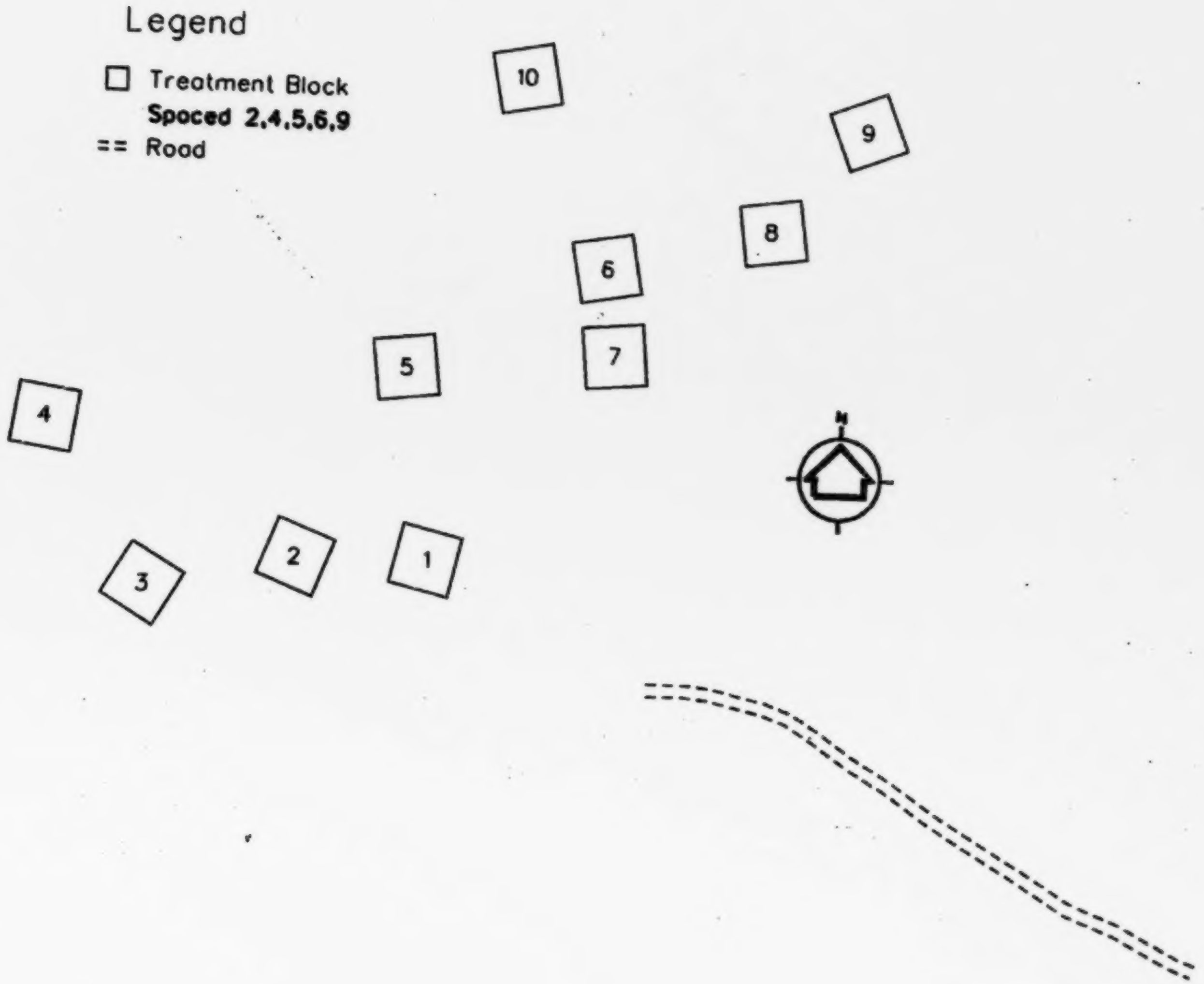
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LUSSIER CREEK

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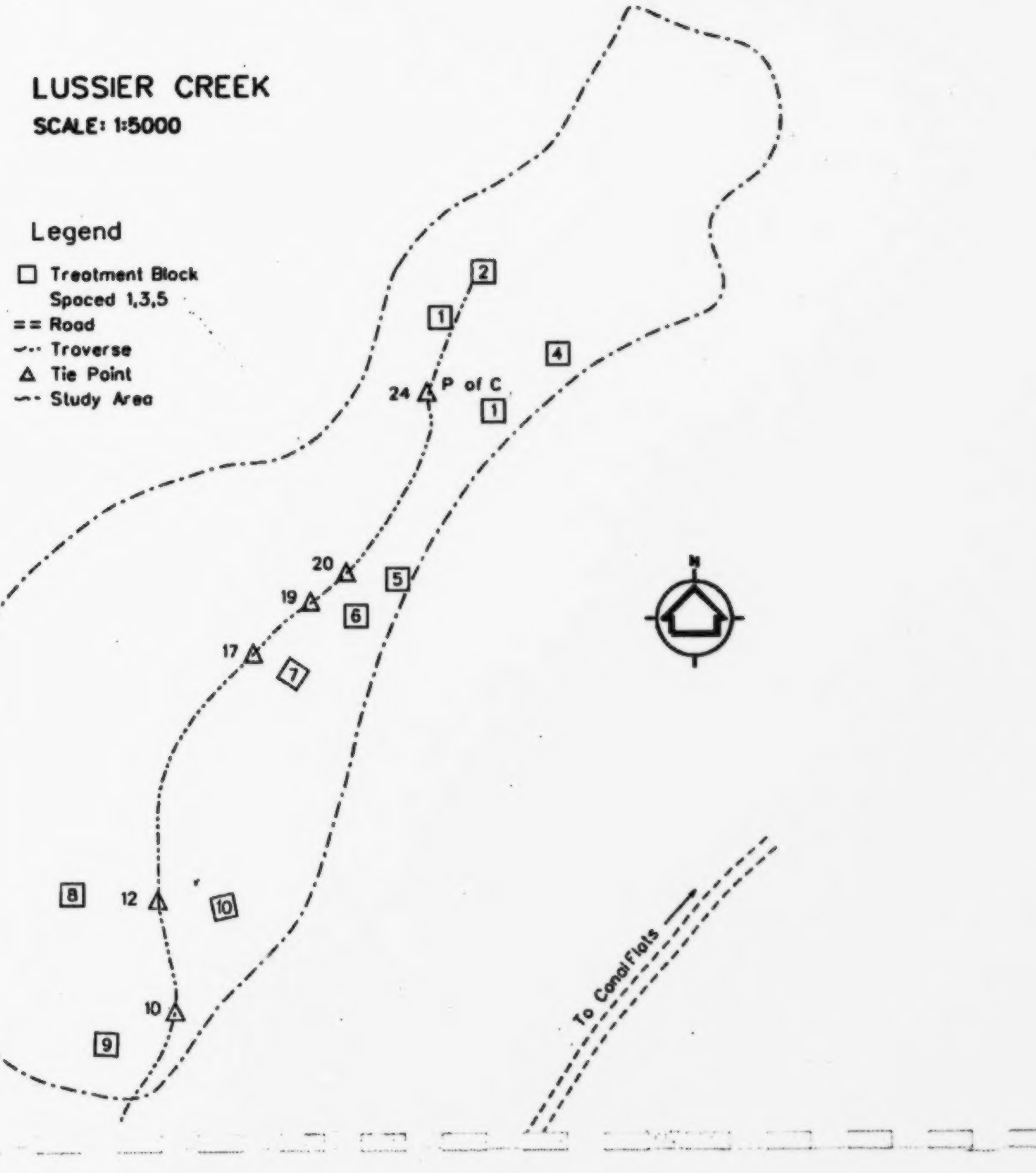
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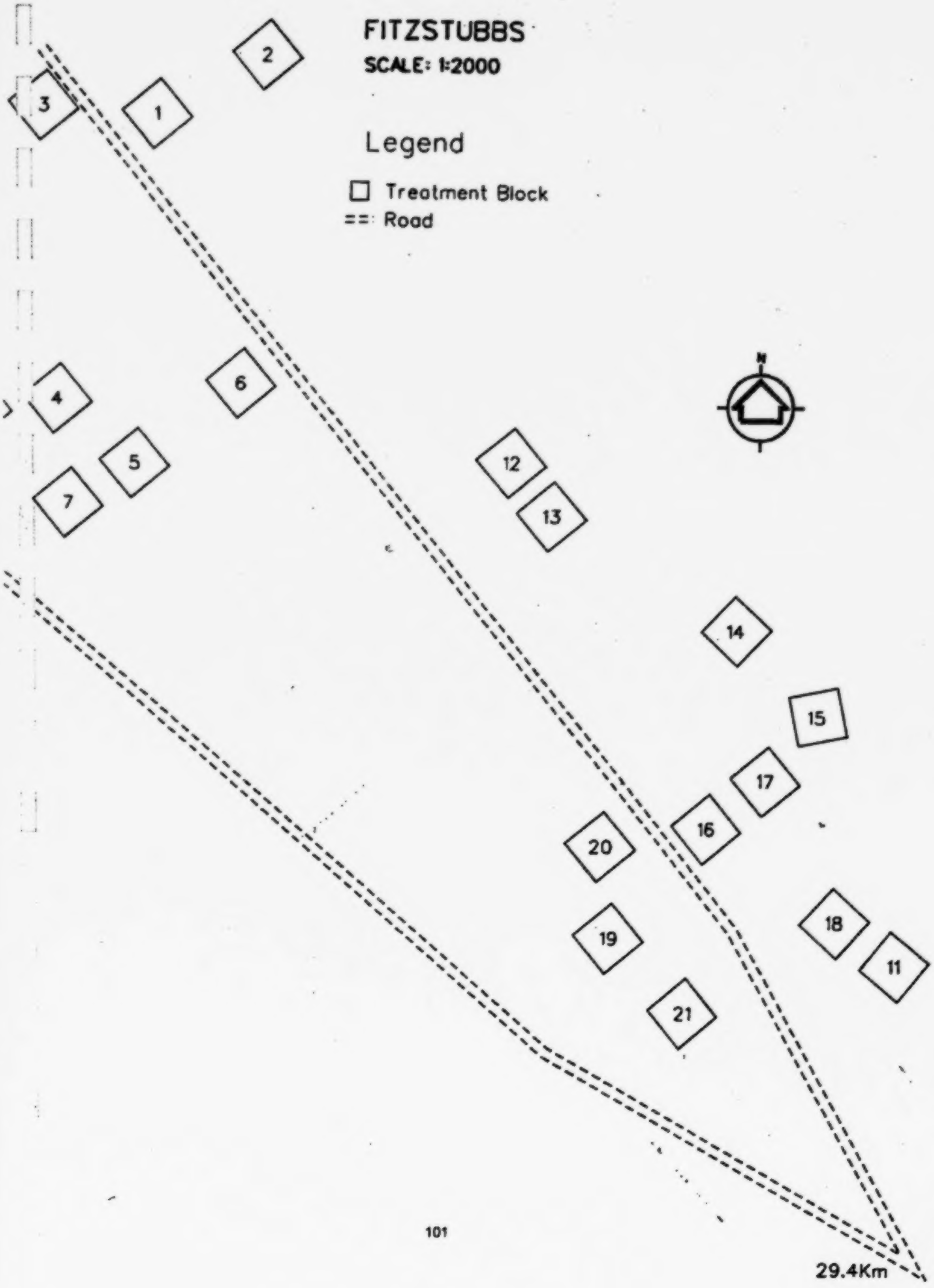

FITZSTUBBS

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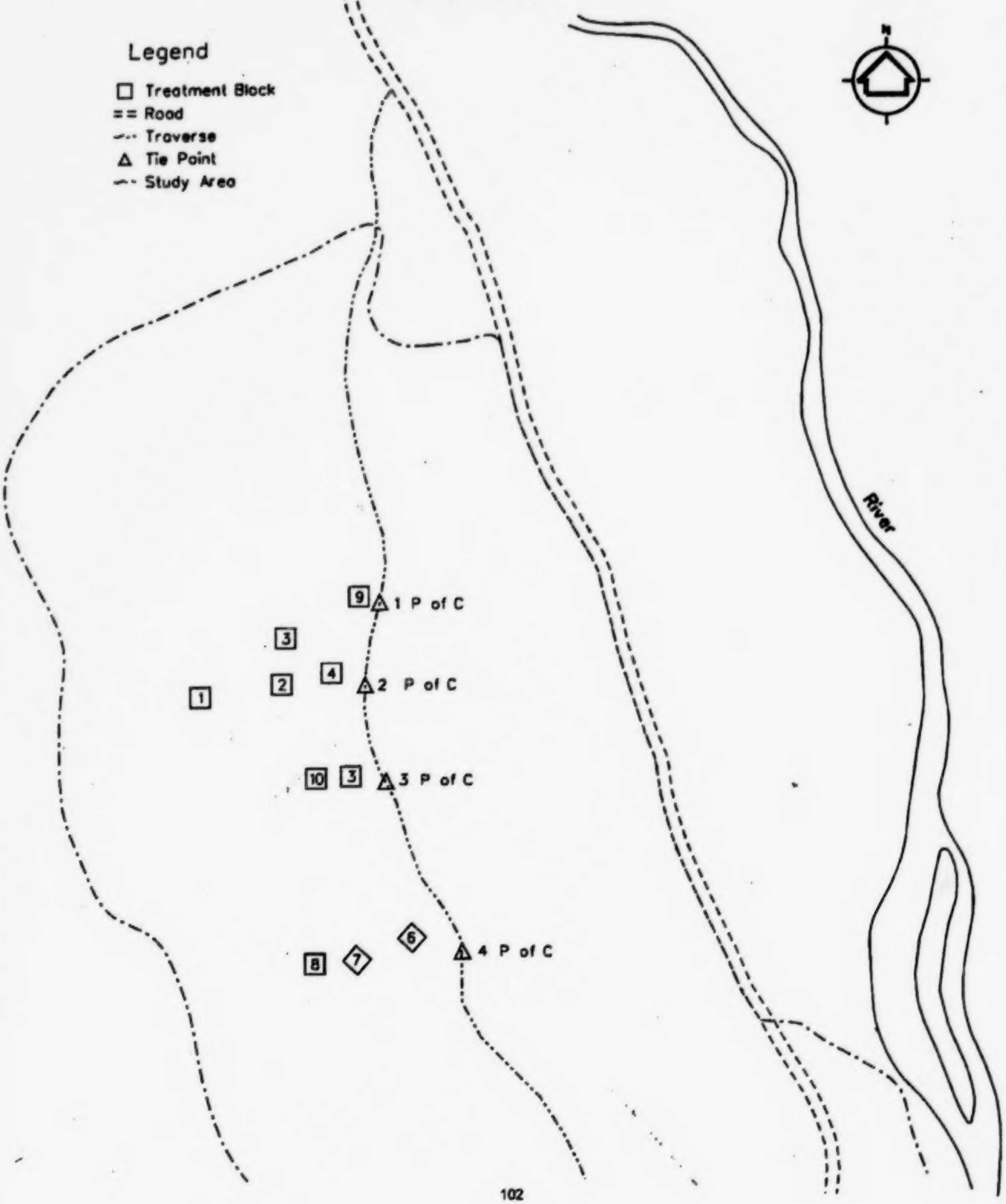
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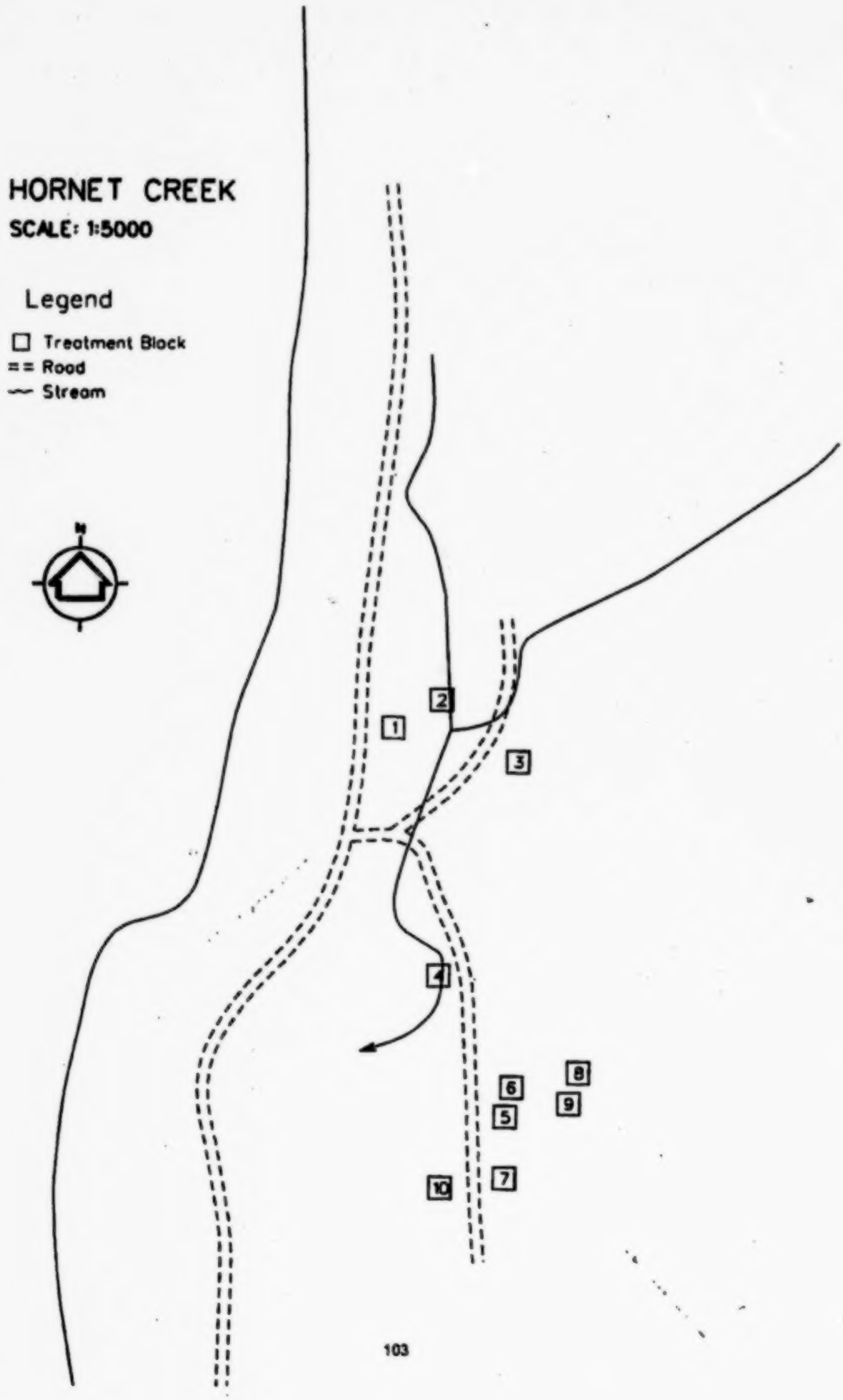
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TALCHAKO

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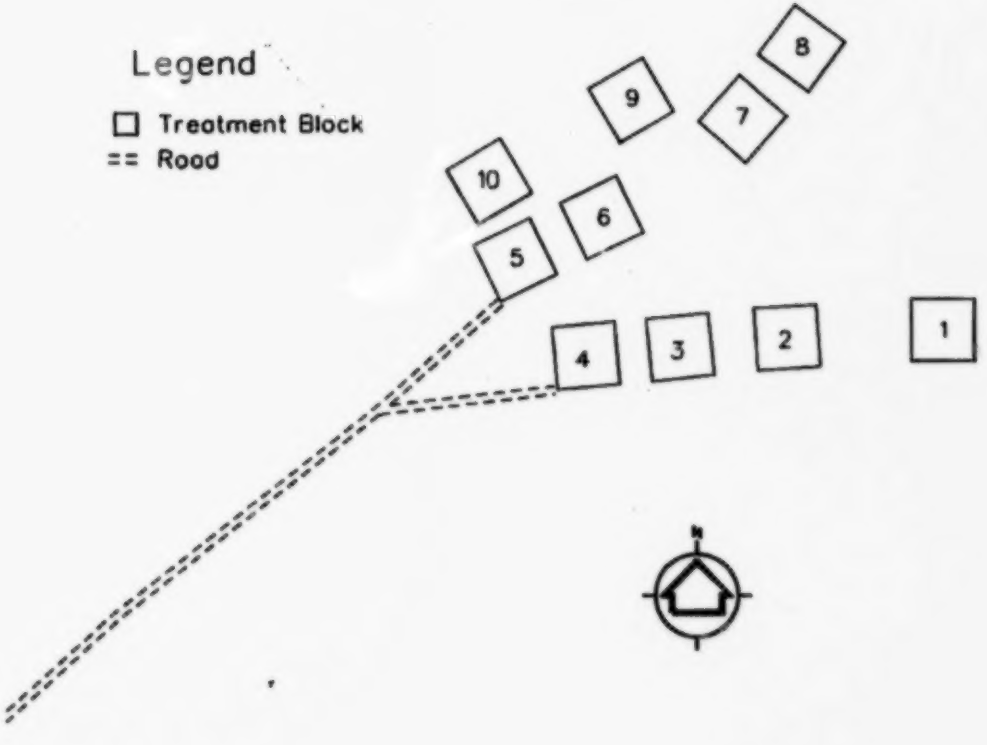
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SUMMARY 22

Project

Armillaria Development Plots—Sugar Lake and Nakusp

Author(s)

D. Morrison

Study Objectives

1. Document the development of *Armillaria ostoyae* in Douglas-fir plantations.

Overview

Layout and Treatments

See Table 22-a for site descriptions.

Site selection criteria included uniformity of site characteristics, uniform stand stocking, stand age between 15 and 20 years, and uniformity of Armillaria distribution and intensity. Within each site, a 2-ha area was selected for study. For ease of monitoring, 2-ha study areas were divided into eight 50x50-m blocks. Information on pre-harvest Armillaria incidence is unavailable.

Measurements

Within each 50x50-m block, all live trees were examined for Armillaria symptoms, i.e. basal resinosis and mycelial fans. Dead trees were examined and cause of death determined. All trees, live and dead, were tagged. All dead and infected trees were stem mapped using x and y coordinates, and all dead trees were aged.

Analyses

Disease centers were reconstructed by identifying the cause of death, year of death, and location. Further analyses will be undertaken to quantify mortality; disease area; and tree response, i.e. proportion of infected trees that develop callus at root collar.

History/Time Table

1984	Site selection.
1984	Sugar Lake plot layout.
1986	Nakusp plot layout.
1986	First measurements.
1986	Second measurements; re-assessed in even-numbered years.

Status

Ongoing.

Brief Summary of Results

Sugar Lake

Mortality started at age six (2 trees/ha/y), increased rapidly until age ten (35 trees/ha/y) and then levelled off (17 trees/ha/y). Disease centers are associated with old stumps, and generally consist of one or more dead trees. At age 25, about 80 disease centers/ha were evident; these centers represented 22.5% of the total plot area. About 22% of planted Douglas-fir trees had been killed and another 6% infected by age 25.

Nakusp

Disease centers are continuing to spread. Further analysis is in progress.

Working Plans/Reports/Publications

Sugar Lake

Morrison, D. and K. Pellow. 1994. "Development of Armillaria root disease in a 25 year old Douglas-fir plantation" pp.560-571 in M. Johansson and J. Stenlid (eds.), Proceedings of the Eighth Union of Forestry Research Organization (IUFRO) International Conference on Root and Butt Rots. Sweden and Finland, August 9-16 1993.

Peet, F.G., D.J. Morrison, and K. Pellow. 1996. Rate of spread of *Armillaria ostoyae* in two Douglas-fir plantations in the southern Interior of British Columbia. Can. J. of For. Res. 26: 148-151.

Maps

None.

Table 22-a. Site descriptions.

	Site	
	Sugar Lake	Nakusp
Region	Kamloops	Nelson
District	Vernon	Arrow
Opening No.	82L038 - 6	82K022-26
Plot Lat/Long	50^{o}22'N 118^{o}35'W	50^{o}16'N 117^{o}46'W
Study Area (ha)	2	2
Biogeoclimatic Subzone/ Site Series	ICH mw2 01	ICH m..2 01/04
Slope (%)	10-50	5
Aspect	E	SE-E
Species Composition/ Age(y)/Site Class	OS: PL: Fd$_{10}$/27/x	OS: PL: Fd$_{10}$/22/x
Total Stems/ha (no.)	PL: 1700	PL: 1075
Terrain/Soil Class./ Soil Texture	x/x/SL	x/x/SL
Diseases/Insects	DRA	DRA
Stand History	logged 1963; burned 1963; planted 1967	logged 1971; burned 1971; planted 1972
Study Establishment	1984	1986
Treatment	none	none

See Appendix C for abbreviations.

SUMMARY 23

Project

Control of Armillaria and Phellinus Root Disease: 20 Year Results from the Skimikin Stump Removal Experiment[25]

Author(s)

D. Morrison

Study Objectives

1. Determine the effectiveness of stump removal for reducing losses to Armillaria and Phellinus root diseases.
2. Evaluate the resistance of several tree species to the root disease.
3. Test the effect of alternate rows of resistant and susceptible species on disease spread.

Overview

Layout and Treatments

See Table 23-a for site descriptions.

Two adjacent 80x160-m blocks were laid out as control and stumped areas. In the control, trees were conventionally harvested; in the stumped area, trees were pushed over with a bulldozer and yarded to the landing with roots attached. This block was then root raked to a depth of 45 cm using a bulldozer fitted with a toothed, land-clearing blade.

Each block was divided into 32 plots, each 20x20-m (0.04 ha) square. The plots in each block were randomly selected for planting with the species combinations shown in Table 23-a. Seedlings were planted at a 1.5-m spacing, usually with 13 rows of 13 trees in each plot. Except for cedar and birch, all seedlings were nursery-grown, 2+0, bareroot stock. Cedar and birch were wildlings from the vicinity of the trial area.

Measurements

In 1973, each plot was stem mapped using x and y co-ordinates, and the condition of each tree was recorded as healthy, dead, or damaged. Mortality and damaged were identified to cause, i.e. insect, disease, abiotic, mammal. Armillaria infection was based on lower bole and root collar basal resinosis and mycelial fans.

Tree condition was reassessed in 1977, 1981, 1983, 1987, and 1992. Dbh was recorded for all trees in 1987, and heights were measured on four randomly selected dominant or co-dominant trees of each conifer species, except cedar, in each plot.

Analyses

Descriptive statistics were used to summarize species and block height and cumulative mortality. For Douglas-fir and lodgepole pine, cumulative mortality by block was analyzed using ANOVA, following application of the arcsin transformation. (It was acknowledged that the experimental design, with one replication per block, did not adhere to the assumptions of an

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[25] The Skimikin experiment was intended to test the efficacy of stump removal for control of *Phellinus weirii*. This summary focuses only on the Armillaria component.

ANOVA.) Differences in mean cumulative mortality for larch, spruce, cedar, and birch were not statistically tested. Discussions of treatment effect for these species were based on mean values.

Douglas-fir and lodgepole pine dbh and height were analyzed by ANOVA. Graphical analysis was used to evaluate treatment effectiveness in reducing disease centers.

History/Time Table

1969	Study establishment.
1973	First measurements.

Subsequent assessments until 1987 were inconsistent. Assessments will now be undertaken every fifth year (last measured in 1992).[26]

Status

Ongoing.

Brief Summary of Results (up to 1987)

Mortality Caused by Root Diseases

Cumulative percent mortality in 1987 for *Armillaria ostoyae* was significantly less ($P<0.01$) in the treated block than in the untreated block for both Douglas-fir and lodgepole pine.

For larch and spruce, mean commutative percent mortality caused by *Armillaria ostoyae* was higher and lower, respectively, than that of Douglas-fir or lodgepole pine in both blocks. No birch or cedar were killed by Armillaria in the treated block; one birch and thirteen cedar were killed in the control.

In the control, *Armillaria ostoyae* mortality in Douglas-fir and lodgepole pine occurred at a constant rate of 1% per annum from 1973 to 1987. The mortality rate in the treated block was constant also, at 0.1% per annum in lodgepole pine and 0.2% in Douglas-fir.

The relative susceptibility of the confer species to *Armillaria ostoyae,* as indicated by cumulative percent mortality in the untreated block, was as follows: larch>lodgepole pine>Douglas-fir>spruce>cedar.

Spatial Distribution of Root Disease Mortality

Compared to the control, the stumped block had a reduced number of one- and two-tree centers, and no centers with three or more trees. Alternating rows of fir or pine and cedar or birch reduced the spread of *Armillaria ostoyae* centers between rows, reducing the size of disease centers.

Growth of Douglas-Fir and Lodgepole Pine

For both Douglas-fir and lodgepole pine, dbh and height were significantly greater ($P<0.01$) in the treated block than in the untreated block. The mean height and diameter of spruce and larch also were greater in the treated block.

For Douglas-fir and lodgepole pine, the increased growth was attributed to a reduction in competition from herbs and shrubs and perhaps of improved soil nutrient status through mixing of organic matter.

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[26] The 1993 results are not included in this summary.

Working Plans/Reports/ Publications

Morrison, D., G. Wallis, and L. Weir, 1988. Control of Armillaria and Phellinus root diseases; 20 year results from the Skimikin stump removal Experiment. PFC, CFS, Victoria. Information Report BC-X-302. 16 p.

Maps

Refer to above report.

Table 23-a. Site descriptions.

	Site	
	Skimikin	Skimikin
Region	Kamloops	Kamloops
District	Salmon Arm	Salmon Arm
Opening No.	NA	NA
Plot Lat/Long	50°48N/119°26'W	50°48'N/119°26'W
Study Area (ha)	1.25	1.25
Biogeoclimatic Subzone/	ICH mw2	ICH mw2
Site Series	x	x
Slope (%)	5	5
Aspect	S	S
Species Composition/ Age(y)/ Site Class	OS: Fd_8Pl_2(EpAtCw)/80/x PL: varied/ 25 /x	OS: Fd_8Pl_2(EpAtCw)/80/x PL: varied/25/x
Total Stems/ha (no.)	OS: unk PL: 1183	OS: unk PL: 1183
Terrain/Soil Class./Soil Texture	GF/ EB/x	GF/ EB/ x
Diseases/Insects	DRA, DRL	DRA, DRL
Stand History	natural, logged 1969	natural, logged 1969
Study Establishment	1968	1968
Treatment	Stumped	Unstumped

See Appendix C for abbreviations.

SUMMARY 24

Project **Species of Armillaria in British Columbia**

Author(s) D.J. Morrison, D. Chu, and A.L.S. Johnson

Study Objectives 1. Determine the Armillaria groups occurring in BC, their hosts and distributions, and their relationships to species found elsewhere.

Overview

Layout and Treatments

Identification of Species in BC

Infertility studies were conducted during four fruiting seasons. In season one, basidiocarps were collected from 37 locations in BC. Mating types among single spore isolates from each collections, i.e. stock, were determined by pairing 12 isolates in all combinations. The four mating types from each of 3 to 5 stocks from a limited geographical area were paired in all combinations. Testers of incompatible stocks were paired with those from other geographic areas until the number of intersterile groups was determined. In the second, third, and fourth seasons, two monosporous cultures from 162 basidiocarps (68, 64, and 30, respectively) were paired with the testers from each intersterile group (identified in season one).

Compatibility of BC Species with European Species

Armillaria testers from Britain (*Armillaria mellea, Armillaria bulbosa* and *Armillaria ostoyae*), and Germany (*Armillaria borealis* and *Armillaria cepistipes*) were paired with intersterility groups from BC.

Compatibility of BC Species with North American Intersterility Groups

Testers of four intersterile BC groups were paired with testers from North American groups (see Anderson and Ullrich 1979 for a description of these groups).

Measurements

Identification of Species in BC

Basidiospores were discharged from all basidiocarps collected in BC. These were discharged onto water agar in petri dishes and after 36-48 hours germinated spores from each collection, i.e. stock, were transferred to slants of 1.25% malt extract agar. For each stock, the host species and condition were recorded, i.e. as living or dead, and standing tree or stump. A piece of basidiocarp stipe or colonised host tissue was placed on malt extract agar amended with benomyl (Hunt and Cobb 1971).

Compatibility of BC Species with European and North American Intersterility Groups

See description of Layout and Treatments, above.

Analyses

Within an intersterility group, the appearance of compatible, incompatible, and semi-compatible mating reactions were determined according to methods described by Korhonen (1978). Pairing between monosporous cultures from different intersterility groups was indicated by a line of brown pigment.

History/Time Table

N/A.

Status

Complete.

Brief Summary of Results

Identification of Species in BC

Five intersterile groups, designated A to E, were identified among the 37 first-season stocks. During the second season, a sixth group F, was collected.

Compatibility of BC Species with European Species

Pairing of tester cultures from BC groups A to F with three species from Britain and two species from Germany revealed which isolates were compatible, i.e. by pairing yielded crustose mycelia (Table 24-a).

Compatibility of BC Species With North American Species

Pairing of tester cultures from BC groups A to F with North American groups revealed which isolates were compatible (Table 24-b).

Five of the ten North American intersterility groups identified by Anderson and Ullrich (1979) were found in BC, in addition to a previously uncollected group (F). The authors state that *Armillaria ostoyae* is moderately to highly pathogenic; this contrasts with the other groups, which are weakly pathogenic. They note that the division of *Armillaria* into intersterile groups does not explain the differences in the amount and duration of mortality between Coastal and Interior conifer stands. They conclude that future work should determine the relative pathogenicity of BC groups and examine the variation within *Armillaria ostoyae*.

Working Plans/Reports/ Publications

Morrison, D.J., D. Chu, and A.L.S. Johnson. 1985. Species of Armillaria in British Columbia. Can. J. Plant. Path. 7:242-246.

Maps

A map showing the distribution of the following Armillaria groups in BC is provided in the above publication: *Armillaria bulbosa*, groups IX and F; Group V; and *Armillaria ostoyae*.

Table 24-a. Test cultures: Pairing of BC Armillaria species with European species.

BC group	Collection location(s)	Host	European species
B	Southwestern BC (CDF zone)	Live/dead broadleaved spp.	*A. bulbosa* (Britain)
D	Province-wide (49-53° lat.)	Conifers/broadleaved spp.	*A. ostoyae* (Britain)
F	Hope and Stewart, BC	Broadleaved spp.	*A. cepistipes* (Germany)

Figure 24-b. Test cultures: Pairing of BC species with other North American species.

BC group	Collection location(s)	Host	North American group
A	Province-wide (49-57° lat.)	Dead/broadleaved spp.	V
B	Southwestern BC (CDF zone)	Live/dead broadleaved spp.	VII (*A. bulbosa*)
C	Southwestern BC (CDF zone)	Live/dead broadleaved spp.	IX
D	Province-wide (49-53° lat.)	Conifers/broadleaved spp.	I
E	Nelson and Fernie, BC	conifers	X

SUMMARY 25

Project EP 370b

Partial Cutting in the Columbia Forest Zone (ICHb)

Author(s) J. Pollack

Objectives

1. Examine the growth and yield response of a mid-seral ICHwk1 stand subjected to various types of partial cutting.

2. Examine regeneration and pathology of a mid-seral ICHwk1 stand subjected to various types of partial cutting.

Overview

Layout and Treatments

See Table 25-a for site description.

The following four treatments were tested in a randomized block design:

- *Treatment 1, Improvement cut.* Thinning of clumps, release of high stems, removal of low-value trees without damage to residuals or prejudice to full stocking. Cutting was restricted to trees >20-cm dbh.
- *Treatment 2, Diameter limit cut.* Removal of trees above a certain diameter class such that basal area removed approximately equalled the basal area removed in Treatment 1. Resulting diameter limit ranged from 35.6 to 40.6 cm, depending on the block.
- *Treatment 3, Salvage cut.* Removal of all hardwood species, larch, and white pine, except for approximately 5 larch/ha and 5 white pine/ha for a seed source. Cutting was restricted to trees >20-cm dbh.
- *Treatment 4, Control.* No cutting.

Five replicates of each of the four treatments were established in 1957 for a total of 20 square plots, each measuring 0.101 ha. One plot was harvested in 1989, leaving Treatment 3 with only four replicates.

Measurements

Growth and Yield

All trees in plots were permanently tagged and revisited at five-year intervals for re-measurement and assessment of mortality. For each tree, the species, height, and dbh at 1.37 m were recorded. In 1990, a permanent grid was established in each plot, and plots were stem mapped using an x-y coordinate system.

Regeneration

In 1990, regeneration was assessed on 50 m^2 subplots within the larger plots. Regeneration subplots were distributed such that 16 were positioned in a 4x4 grid within the 0.101-ha plots. Measurements of total stems/ha, free-growing stems/ha, and well-spaced stems/ha were taken on each regeneration subplot.

Pathology

In 1990, all tagged trees in plots were examined for above-ground symptoms of root disease (e.g. shortened needles, shortened leaders, rounding of the crown, chlorosis, basal resinosis and "cat faces" or dead tissue at the base of the tree) and placed in one of five symptom classes. The root disease classification system was later calibrated for each tree species and pathogen, to estimate the degree of infection represented by the different symptom classes. For each conifer species present, the roots of at least five trees within each symptom class were excavated to determine the presence and extent of fungal hyphae invasion. Excavation concentrated on the root collar and major roots a distance of one metre from the bole. The percent of trees infected with *Armillaria ostoyae* or *Phellinus weirii* within 1 m of the root collar and the percent of trees with main roots infected were noted.

Analysis

Growth and Yield

The overall performance of each treatment was compared by species in terms of periodic annual increment (PAI), volume removed in improvement, diameter limit or salvage cuts, and mortality.

Regeneration

Regeneration in the different treatment plots will be compared with respect to stems/ha, free-growing stems/ha, and well-spaced stems/ha.

Pathology

The proportions of trees found to be infected (based on species-specific calibrations) in the four treatments were compared using a one-way ANOVA. Some trees appeared to display root disease symptoms more readily, therefore Chi-square tests were used to compare the species compositions of the four treatments.

Status

Ongoing.

History/Time Table

Fall 1957	Baseline assessment.
Fall 1962	5-year re-measurement.
Fall 1967	10-year re-measurement.
Fall 1972	15-year re-measurement.
Fall 1977	20-year re-measurement.
Spring 1983	25-year re-measurement.
Summer 1989	One plot destroyed by logging.
Fall 1990	33-year growth and yield re-measurement. Regeneration and pathology assessment.

Brief Summary of Results

Growth and Yield

The salvage treatment produced the highest net volume increment, while removing the highest volume and showing the lowest mortality based on 15-year growth and yield measurements. This result was attributed to accurate recognition and removal of the high mortality risk species (i.e. larch and white pine), removal of many of the hardwoods, and retention of the Douglas-fir (permitting other species to make a significant contribution to the PAI) in the salvage cut treatment. The author advocated additional removal of Douglas-fir, because this species would contribute significantly to the stand volume removed, and because Douglas-fir was not expected to survive to stand maturity due to *Phellinus weirii* infection.

Regeneration

No results available at the present time.

Pathology

Infection rates were high in all treatments with 42 to 57% of trees showing above-ground symptoms. The predominant causal agent was *Armillaria ostoyae* with 84% of symptomatic trees assessed as such, and *Phellinus weirii* was also present at moderate levels at 19% of symptomatic trees). Percent of trees infected did not differ significantly between treatments, both when the two pathogen species were considered independently and when they were combined. Also, Chi-square tests indicated that tree species composition did not vary significantly between treatments. Pathocon Consulting concluded that the partial-cutting treatments had no significant effect on root disease incidence, relative to the control, and that such treatments are therefore viable operations in severely infected stands. They caution that their conclusions are based on the assumption of equal root disease incidence across treatments in the original plots. Root disease sampling was not conducted at the onset of the study, therefore different levels of infection between treatment plots could have masked any treatment effects. They also noted that assessment of causal agents was difficult, because excavation and dissection were not possible.

Working Plans/Reports/Publications

Stewart, M. 1956. Cost study of partial cutting treatments in Interior wet belt of BC. BCFS. Res. Note 32.

Thompson, C. 1977. Partial cutting in a mixed wet-belt type. BCFS. Res. Note 78.

Pathocon Consulting. 1990. Root disease assessment of experimental project EP 370b. Draft Report to BCMOF.

Maps

See following.

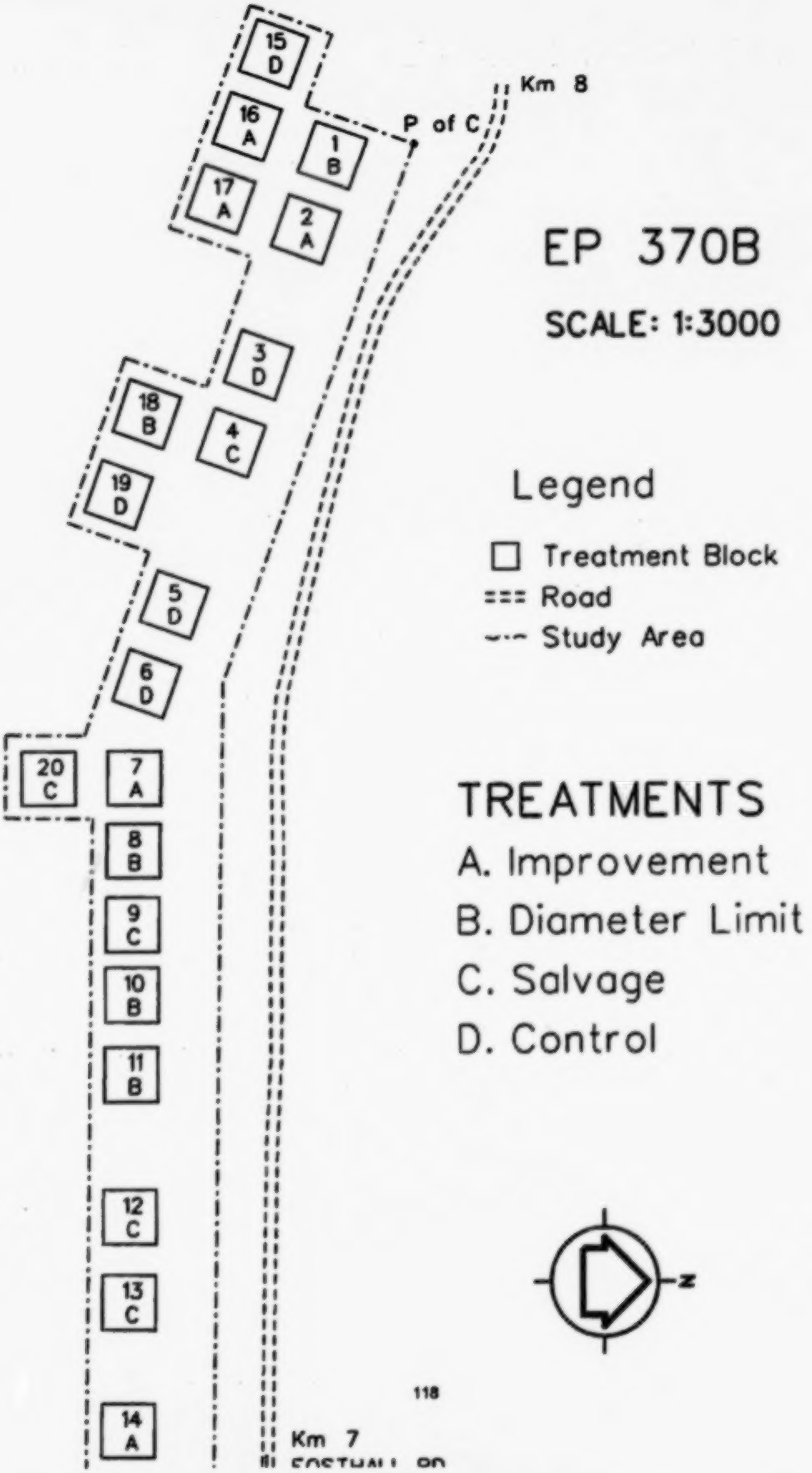
Table 25-a. Site description.

	Site
	Fosthill Creek Road (TFL 23)
Region	Nelson
District	Arrow
Opening No.	
Plot Lat/Long	w
Area (ha)	6.2
Biogeoclimatic Subzone/Site Series	ICHwk1
Slope (%)	5-20
Aspect	N
Species Comp./Age/Site Class	CwHw(PwFdLw)/age class 5/x
Stems/ha (no.)	1023 - 1201
Terrain/Soil Class./Soil Texture	x/x/x
Diseases/Insects	DRA and DRL
Stand History	fire
Study Establishment	1957
Treatment(s)	1. Improvement cut
	2. Diameter limit cut
	3. Salvage cut
	4. No cutting (control)

See Appendix C for abbreviations.

Table 25-b. Root disease classification system.

Symptom Class	Description of above-ground symptoms	Description of the degree of infection, from calibration of symptom classes
0	Healthy	Free of infection within 1 m of bole
1	Located within 5 m of an infection source	N/A (no trees were assessed as Class 1)
2	Crown symptoms	Fairly extensive invasion of one or more major roots within 1 m of bole
3	Basal resinosis (< 50% of the circumference)	Root collar infected
4	Basal resinosis (> 50% of the circumference)	Root collar heavily infected
5	Recently dead due to root disease	Root disease invasion of all the major roots, often extending to the root collar


15 D
Km 8
16 A
P of C
1 B
17 A
2 A
3 D
18 B
4 C
19 D
5 D
6 D
20 C
7 A
8 B
9 C
10 B
11 B
12 C
13 C
14 A
Km 7
FOSTHALL RD
N

EP 370B

SCALE: 1:3000

Legend

☐ Treatment Block
=== Road
-·- Study Area

TREATMENTS

A. Improvement
B. Diameter Limit
C. Salvage
D. Control

SUMMARY 26

Project **Operational Feasibility Stumping Trials on Armillaria Root Disease-Infected Stands in the Golden TSA (1983)**

Author(s) L.D. Price and R.W. Hardy

Objectives

Donald Station

1. Determine the economic feasibility of stumping as a condition of a salvage harvesting contract at no cost to the BCMOF.

2. Assess and compare site impact, cost, and productivity of stumping with tracked excavators and crawler-tractors.

Marl Creek

3. Determine and compare productivity, cost, and site impact of stumping with D7G and D8K crawler-tractors equipped with brush blades.

Overview

Layout and Treatments

See Table 26-a for site descriptions.

At the Donald Station site, two areas were selected for treatment. At one site, harvesting was followed by stumping with a tracked excavator, and at the other site harvesting was followed by stumping with a crawler-tractor. Timber in these areas was disposed of under salvage tenure with the contract condition that all stumps be rolled out of the ground with minimal breakage and site disturbance.

The Marl Creek site was clearcut and then stumped with two crawler-tractors of different sizes.

Measurements

Productivity and Costs

Donald Station. Costs for harvesting, hauling, road maintenance, and the stumping treatment were combined to produce a rough total cost figure. Cost for each of these phases was determined by multiplying machine productivity (hours machine worked) by the contractor rate. A total profit figure was determined by subtracting the total cost figure from the total selling price of the wood harvested.

Marl Creek. For this operation, only the costs for the stumping treatment were evaluated. Productivity (total hours of machine time) was multiplied by hourly rates for each of the two machines used. These figures were divided by the number of hectares stumped to generate a cost/ha for each machine.

Soil Disturbance

Donald Station. A general visual assessment of soil displacement, compaction, and root breakage was conducted.

Marl Creek. A general visual assessment of soil disturbance was conducted. In addition, a soil disturbance survey was undertaken by the Pacific Forestry Centre. In this detailed study, the extent, type, and degree of soil disturbance was assessed using a point-transect method. Points were spaced at 3-m intervals along transects surveyed across the clearcut using a system of grids described in Bloomberg et al. (1980). A total of 880 points were classified over approximately 2660 m of line. Data collected at each point included: slash, debris, slope, aspect, macro and micro relief, moisture regime, humus depth and type, free carbonate, and soil disturbance type and depth. At every tenth point, a mil-acre vegetation plot was established and the following information was collected: species, percent cover, vigour, and distribution. At every twentieth point, a mil-acre regeneration plot was established. Measurements included the above vegetation descriptions and measurements of seedling height and quality. Further study of specific soil disturbances (e.g. soil strength and bulk density) was also undertaken and these results are presented in Summary 40.

Analysis

For Donald Station and Marl Creek, qualitative comparisons were made for soil displacement, compaction, and root breakage observed among treatments.

History/Time Table

Fall 1982	Marl Creek site harvested.
Spring 1983	Donald Station site harvested and stumped.
	Marl Creek site stumped.
Fall 1983	Post-treatment soil disturbance surveys.

Status

Complete.

Brief Summary of Results

Productivity and Costs

Donald Station

The total cost of the operation (including harvesting, hauling, road maintenance, and stumping) was \$24,016 or \$21.85/m^{3}. Total selling price of the wood harvested was \$31,978 for a profit of \$7,961.50. The stumping costs were approximately 17% of the total cost at \$3.64/m^{3}.

Marl Creek

The cost per hectare for stumping with the D7G and D8K crawler-tractors was \$509.03 and \$561.84, respectively. Both machine operators felt that productivity could have been improved by about 20% if the stumping treatment had been done later in the summer when soil moisture content would have been lower.

Soil Disturbance

Donald Station

Residue loading on treatment unit no. 1 was high. Based on the visual assessment, soil disturbance was lowest with the tracked excavator. This was attributed to the pulling action of the tracked excavator versus the pushing rolling action of the crawler-tractor. While both sites had a significant cedar and balsam understory, no further treatment was required after stumping with the crawler-tractor, because sufficient plantable spots and a prepared seed bed were evident. On the site stumped with the tracked excavator, piling and burning of debris was required. The author recommended stumping operations be conducted on snow or when soil moisture is low to reduce compaction and puddling. Other recommendations were to: roll rather than push stumps when using crawler-tractors, in order to avoid excessive soil displacement; and put displaced soil back into the hole resulting from stump removal, when using tracked excavators.

Marl Creek

Based on a visual assessment, acceptable site-disturbance levels were evident on dryer, deeper, soiled slopes up to approximately 30%. Unacceptable impact levels resulted on shallow soiled slopes in excess of 30% and on moist areas of the block. The unacceptable site disturbance was attributed to the pushing and lifting action of the crawler-tractors which caused the tracks of the machines to swivel and churn. The D7G had greater impact on the moist, shallow soiled areas; this was attributed to lower horsepower and weight relative to the D8K. The latter machine was able to break stumps free without spinning the tracks.

The authors recommended:

- using larger high-horsepower machines (D7 or equivalent) and experienced machine operators,
- conducting operations when soil moisture is low and avoiding wet areas at all times,
- using available information from soil surveys, maps, and field checks to stratify the block based on soil sensitivity and maximum workable slope, and
- clean skidding or burning sites with heavy slash loading to improve stumping efficiency and quality.

Results from the line transect survey showed that 69% of the clearcut was stumped and 86% of the stumped area was disturbed. Of the disturbed points, 51% were deposits, 48% were gouges, and 1% were a mixture of the two. A large proportion of the gouges were deep (5-25 cm) or very deep (>25 cm). Approximately half of the disturbance was caused by stump removal, while 34% was caused by tractor tracks. Other disturbances—including skid roads, fireguards, scalps, and crawler-tractor trails—made up the remainder. In the unstumped area of the block, 41% was disturbed.

Working Plans/Reports/ Publications

Price, L.D. and R.W. Hardy. 1984. Operational feasibility stumping trials on Armillaria root disease infected stands within the Golden TSA 1983. BCMOF. Internal Report PM-N-2.

Smith, R.B. and E.F. Wass. 1985. Changes in soil surface conditions at Marl Creek root-rot control site. PFC, CFS. Victoria. Internal Report.

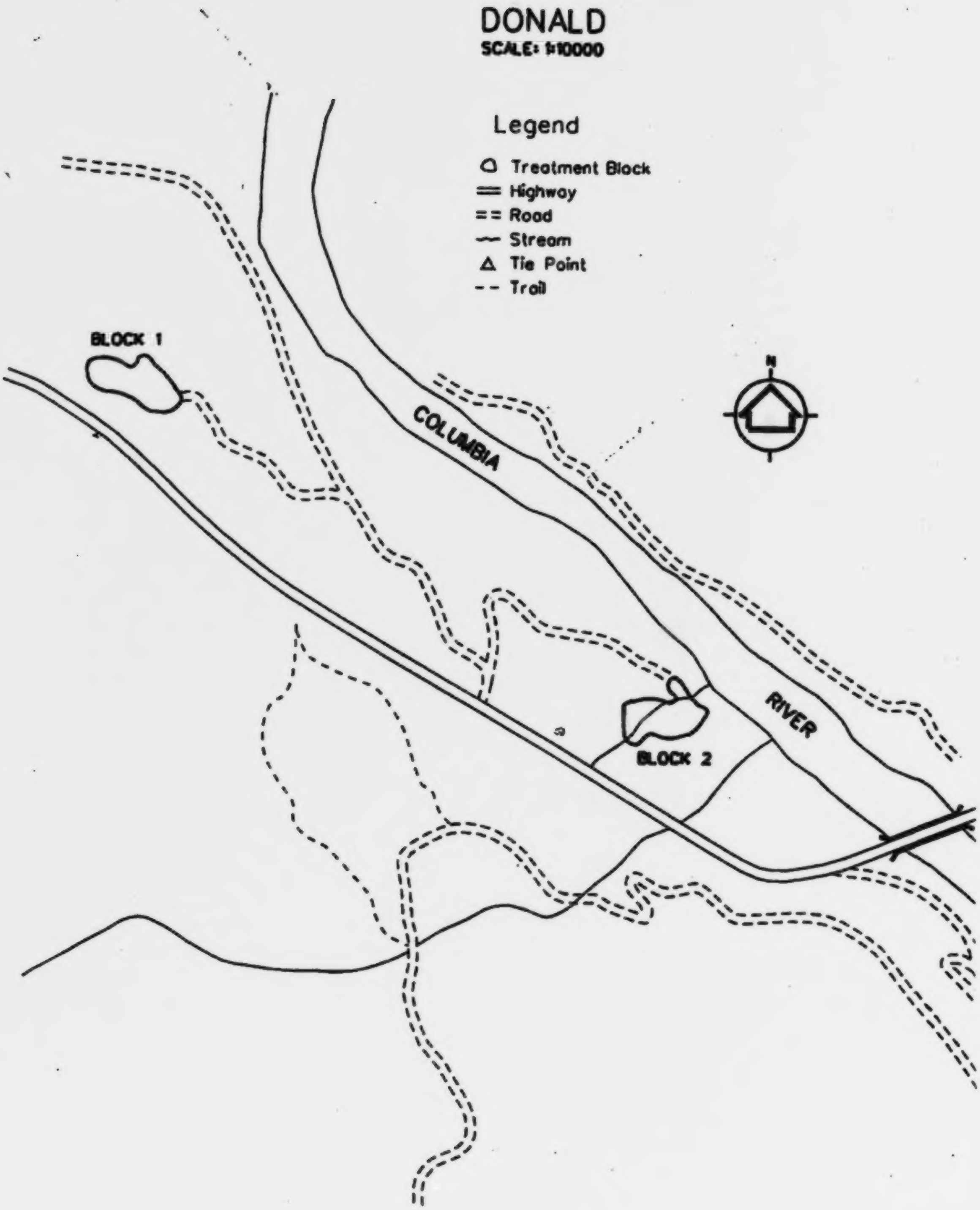
Maps

See following.

Table 26-a. Site descriptions.

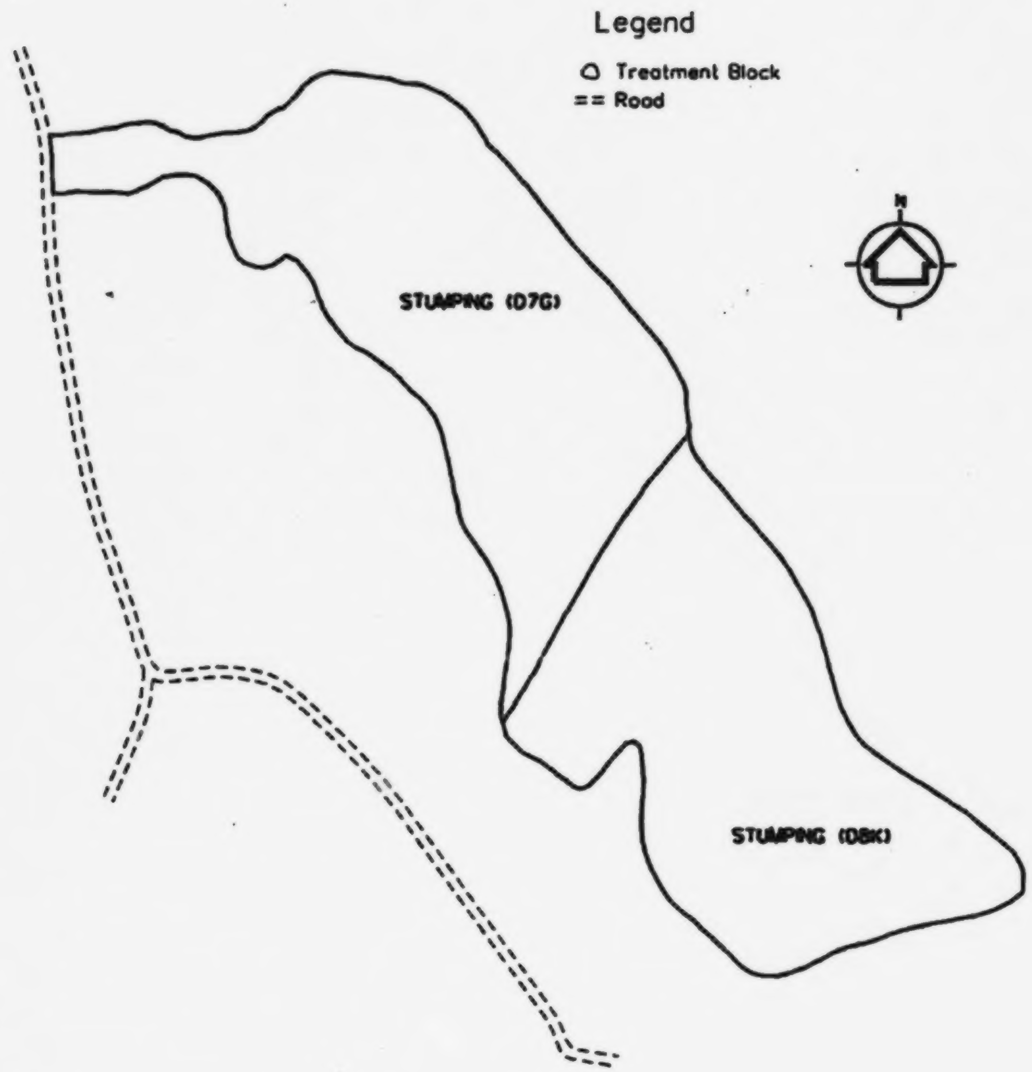
	Site			
	Donald Station 1	Donald Station 2	Marl Creek 1	Marl Creek 2
Region	Nelson	Nelson	Nelson	Nelson
District	Golden	Golden	Golden	Golden
Opening No.	82N6G		B2N054195	CP20 FLA17645
Plot Lat/Long	51°29' N 117°13' W	51°29' N 117°13' W	51°33' N 117°11' W	51°33' N 117°11' W
Area (ha)	2	2	12	14
Biogeoclimatic Subzone	ICHmw1	ICHmw1	ICHa2	ICHa2
Slope (%)	5-25	5-25	19	5-40
Aspect	NE	NE	SW	NW
Species Comp./Age/Site Class	FdSxCw(Pl)/x/x	FdSx(Cw)/x/x	FdPlSx(At)/x/x	FdPlSx(At)/x/x
Stems/ha (no.)	total: 965 + 58 snags	total: 658	total: 573 + 95 snags	total: 573 + snags
Terrain/Soil Class./Soil Texture	x/x/deep silty clay	x/x/deep sandy loam	x/x/deep to shallow silty clay loam	x/x/deep to shallow silty clay loam
Diseases/Insects	DRA (36%F; 20%S)	DRA, DRT (75%F; 60%S)	DRA	DRA
Stand History				
Study Established	1983 H: spring 1983 S: spring 1983	1983 H: spring 1983 S: spring 1983	1983 H: fall 1982 S: spring 1983	1982 H: fall 1982 S: spring 1983
Treatment(s) H: harvesting S: stumping	H: JD 550 crawler-tractor S: 1967 model 300 poclain tracked excavator and 1969 model 20H Bucyrus Erie tracked excavator	H: JD 550 crawler-tractor S: D7G caterpillar crawler-tractor with brush blade	H: crawler-tractor, rubber-tired skidder, hand-felled S: 1980 D7G, 200 FWHP (149kw) crawler-tractor	H: crawler-tractor, rubber-tired skidder, hand-felled S: 1978 D8K, 300 FWHP (224kw) crawler-tractor

See Appendix C for abbreviations.


DONALD
SCALE: 1:10000
Legend
Treatment Block
Highway
Road
Stream
Tie Point
Trail
N
BLOCK 1
COLUMBIA
RIVER
BLOCK 2

MARL CREEK

SCALE: 1:5000


Legend
○ Treatment Block
== Road
N
STUMPING (D7G)
STUMPING (D8K)

SUMMARY 27

Project **Determination of Compaction and Characterization of Disturbance Class Morphology for Soil Disturbance Classes Associated with Pushover Logging**

Author(s) L.S. Redfern

Study Objectives For two blocks:

1. Quantify the compaction associated with specific disturbance types occurring on pushover logged blocks.
2. Characterize the morphology of the deep gouge disturbance types created during pushover logging.
3. Determine the level of soil disturbance resulting from pushover logging.

Overview

Layout and Treatments

See Table 27-a for site descriptions.

Two blocks were selected for sampling based on the following criteria: availability, accessibility, pushover logged during the winter of 1993, and an average or better than average level of planning and execution.

Measurements

Surveys of soil disturbance were conducted using a systematic survey point location system. A total of 43 distinct disturbance types were utilized in keying out the soil disturbance at each survey point; some of these were simply divisions of operational soil disturbance survey classes to permit greater resolution of disturbance types for the purposes of research (e.g. deposits separated into depth classes).

At each research site, 100 survey points were randomly selected for sampling, 20 in each of five disturbance classes: Undisturbed, Light Traffic (compact), Light Traffic (non-compact), Heavy Traffic (compact), Heavy Traffic (non-compact).

Soil cores were taken for bulk density (495 cm^3) at depths of 2-8.7 cm and 10-14.7 cm, and for water retention (36 cm^3) at depths of 2-4 cm, 6-8 cm, and 14-16 cm, at each randomly selected point. Bulk density was determined on the large cores using the methods of Blake and Hartge (1986); water retention analyses were done on the small cores using the methods of Klute (1986). Pore-size distribution was determined using the water desorption method as per Danielson and Sutherland (1986). Total porosity was calculated from bulk and particle densities as per Danielson and Sutherland (1986). Aeration porosity was calculated as the percentage of total porosity air-filled at 5.88 kPa and 9.80 kPa to facilitate comparisons with values in the literature.

Twenty points from the deep gouge category were randomly selected for morphological characterization. Measurements included: maximum length, maximum width, and depth and width normal to the maximum length at 1/4, 1/2, and 3/4 of the entire length. The physical characteristics and depth of deposit in the gouge were also recorded.

Analyses

Summary statistics and graphical analysis for each of the main physical properties investigated—i.e. bulk density, aeration porosity, and water storage capacity—will be undertaken for each site on a soil depth / disturbance class basis. This will include bar graphs for each physical property with 95% confidence intervals for each depth and disturbance class. To test for differences among classes, an ANOVA will be used.

The morphological characteristics of the disturbance classes will be presented using summary statistics and graphical analysis. Summary parameters will include: mean maximum depth, length, width, and surface area, and volume of gouges.

The results of the soil disturbance surveys will be compiled and summarized, including an assessment of detrimental and non-detrimental disturbance.

History/Time Table

1992-93	Site selection and field sampling.
1993-95	Data analysis.

Status

Ongoing.

Brief Summary of Results

Data analysis and report preparation are in progress.

Working Plans/Reports/Publications

Redfern, L.S. 1993. Determination of compaction and characterization of disturbance class morphology for soil disturbance classes associated with pushover logging: Working Plan. Nelson Forest Region, BCMOF.

Maps

None. Sites are temporary.

Table 27-a. Site descriptions.

	Site	
	Mud Creek	Colepitts
Region	Nelson	Nelson
District	Invermere	Golden
Opening No.		
Plot Lat/Long		
Study Area (ha)	5	5
Biogeoclimatic Subzone/Site Series	IDF dm2 01	ICH mw1 01
Slope (%)	0	5
Aspect	0	W
Species Compn./Age(y)/ Site Class		
Stems/ha (no.)		
Terrain/Soil Class./ Soil Texture	GF/ EB/ SiCL	x/ H-FP/ SiL - SiCL
Diseases/Insects	DRA	DRA
Stand History	natural, logged 1993	natural, logged 1993
Study Establishment	1992	1993
Treatment(s)	Pushover	Pushover

See Appendix C for abbreviations.

SUMMARY 28

Project **Hazeltine Creek Armillaria Assessment Plot**

Author(s) R. Reich

Study Objectives

1. Determine the rate of disease spread.
2. Determine the rate of tree mortality.
3. Determine the relative host susceptibility in a young Douglas-fir plantation infected with *Armillaria ostoyae.*

Overview

Layout and Treatments

See Table 28-a for site descriptions.

Plot location and size were determined during a previous unrelated study (Reich and van der Kamp 1993) focusing on the relationship between frost and Douglas-fir die back. An uninfected (without Armillaria) control area was identified within 30 m of the infected plot within the same plantation. The infected plot is 120x180 m, and the control plot is based on a large temporary sample plot. A 10x10 grid, marked by cedar stakes, was established in the large infected plot. (Information on layout in control was unavailable.)

Measurements

All planted trees were stem mapped for location. The following individual tree attributes were recorded: species and health class (healthy, symptomatic crown, red foliage, grey (no foliage) and dead blowdown). No information on levels of infection prior to planting was available.

Analyses

Calculations will include annual mortality rate by species. A digital map of stem locations was created in order to calculate rate of disease spread.

History/Time Table

August 1987	First assessment.
Summer 1990	First re-measurement.
August 1995	Second re-measurement.

Status Ongoing.

Brief Summary of Results

In 1986 and 1987, the annual mortality rate was approximately 1% based on the number of trees in the symptomatic class and red class, i.e. recently killed trees with red foliage. The annual mortality climbed to approximately 1.5% in 1988, 2% in 1989, and 2% in 1990. A preliminary assessment of the data collected in August 1995 indicates that the mortality had slowed considerably in the last five years to a fraction of 1%. The rate of disease spread is highly variable in individuals centers. Centers are expanding in a very irregular pattern. Some boundaries do not expand, others advance at over 1 m/y.

Working Plans/Reports/ Publications

Reich, R.W. and B.J. van der Kamp. 1991. Three year re-measurement report. Canadian Plant Disease Survey 71(1):130.

Reich, R.W. and B.J. van der Kamp. 1993. Frost, canker, and die back of Douglas-fir in the central Interior of British Columbia. Can. J. For. Res. 23:373-379.

Maps

In progress.

Table 28-a. Site descriptions.

	Site	
	Hazeltine Creek/Quesnel Lk.	Control plot
Region	Cariboo	Cariboo
District	Horsefly	Horsefly
Opening No.	93A053-14	93A053-14
Plot Lat/Long	52° 28'N, 121° 40'W	52° 28'N, 121° 40'W
Area (ha)	2.16	2.0
Biogeoclimatic subzone	ICHmk3	ICHmk3
Site Series		
Slope (%)	0-10%	0-10%
Aspect	Variable	Variable
Species Compn./ Age (y)/Site Class		
Stems/ha (no.)		
Terrain/Soil Class./ Soil Texture	undulating/x/x	undulating/x/x
Disease/Insects	DRA/DRT	no DRA
Stand History	1973 Fd plantation	1973 Fd plantation
Study Establishment	1995 (summer 1987)	1995 (summer 1987)
Treatment(s)	none	none

See Appendix C for abbreviations.

SUMMARY 29

Project

Robson Valley Armillaria Assessment Plots

Author(s)

R. Reich

Study Objectives

1. Determine the rate of disease spread, the rate of tree mortality, and the relative host susceptibility in several young stands infected with *Armillaria ostoyae*.

2. Establish demonstration sites for training.

Overview

Layout and Treatments

See Table 29-a for site descriptions.

A 50x50-m plot was established at each site in an area that was close to a road, was relatively well stocked, had an average level of *Armillaria* expression, and had uniformity of site factors.

Measurements

Conifers trees (over 2-cm dbh) were stem mapped for location. Attributes recorded included species; pest occurrence; and health class, i.e. healthy, symptomatic, dead, or dead blowdown. No definition for symptomatic was provided. Levels of infection prior to planting are unknown.

Analyses

Terrasoft GIS stem maps were generated in part to permit future calculations of rate of spread, rate of mortality, and probability of infection, based on distance from inoculum for species susceptibility calculations.

History/Time Table

Annual re-measurements were conducted in all three plots. Re-measurements will continue on an annual basis.

Status

Ongoing.

Brief Summary of Results

All three plots have a relatively uniform distribution of root disease. The annual rate of mortality is relatively low at <1 % for all three plots. Rate of spread will not be calculated for some time. Preliminary species susceptibility rankings are unreliable due to the wide range of tree ages in all three plots.

Working Plans/Reports/ Publications

In progress.

Maps None.

Table 29-a. Site descriptions.

	Site		
	Horse Creek	Horse Creek	Packsaddle Creek
Region	Prince George	Prince George	Prince George
District	Robson Valley	Robson Valley	Robson Valley
Opening No.	83DO65-018	83DO65-019	83DO75-002
Plot Lat/Long	52 47 49.82/ 125 09 45.21	52 41 14.86/ 125 00 36.72	52 40 41.62/ 125 01 08.74
Area (ha)	0.25 ha	0.25 ha	0.25 ha
Biogeoclimatic subzone	ICHmm	ICHmm	ICHmm
Site Series			
Slope (%)	25-30%	5%	10%
Aspect	SW	SW	SW
Species Compn./ Age (y)/Site Class			
Stems/ha (no.)			
Terrain/Soil Class./ Soil Texture	x/P/x	x/P/x	x/P/x
Disease/Insects	DRA	DRA, DS	DRA, DS
Stand History	Planted, 1971 (Fd)	naturally regenerated 1975 (7 species)	naturally regenerated, 1980 (Pl,Fd)
Study Establishment	Summer 1991	summer 1991	summer 1992
Treatment(s)	none	none	none

See Appendix C for abbreviations.

SUMMARY 30

Project **Armillaria Inventory of the Robson Valley Forest District**

Author(s) R. Reich

Study Objectives

1. Determine the extent and severity of *Armillaria ostoyae* in the Robson Valley Forest District.
2. Develop a local hazard and risk rating for the Robson Valley District.

Overview

Layout and Treatments

N/A.

Measurements

Phase I

In 1991 an initial effort to determine the extent and incidence of *Armillaria ostoyae* was undertaken. Prior to 1991 the Armillaria ledger in the ICHmm, SBSdh, and ESSFmm of the Robson Valley Forest District contained only a few confirmed sightings. Transect surveys and walk-throughs of approximately 20 plantations and naturally regenerated stands were conducted on the east side of Kinbasket Lake. Stand selection criteria included: relatively well-stocked stands; minimum stand age of 10 years, with preference for ages over 15 years; and species component of Fd, Bl, Sw leading. Details on Armillaria assessment were not provided.

Phase II

To streamline detection, large-scale air photos were tested to determine whether they could be used to reliably detect and quantify Armillaria[27] root disease. A 2500-ha area of predominantly second-growth trees was flown prior to leaf out on April 24, 1992.[28]

The air photos were stratified in the office, and compared with a ground assessment of plots completed in August 1992. Criteria for incidence class stratification were not provided.

Phase III

Low level aerial sketch mapping from rotary wing aircraft was employed to explore the effectiveness of landscape level detection surveys. Flights were conducted after leaf fall in 1992, prior to leaf out in 1993 and after leaf fall in 1993. Size of area flown was not provided.

Root disease incidence was mapped based on air calls. To calibrate ocular estimates, initial air calls were made over areas with known levels of root disease, e.g. in areas surveyed at high intensity, and also over large 100%

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[27] Ground surveys for *Armillaria ostoyae* are time consuming, require experienced surveyors, and are costly.

[28] This study served as an undergraduate thesis project for Tim Qureshi while preparing for a Forestry Degree at UBC. The 1993 report, titled "Detection of Armillaria Root Disease in the Southern Portion of the Robson Valley using 1:5000 Colour Aerial Photographs" is available on request from the Prince George Forest Region.

stem-mapped plots (0.25 ha).

Phase IV

In 1994, all survey information collected over the previous four years was used to create 1:20,000 map sheets of Armillaria infected stands by incidence class for the southern half of the district (70 map sheets). The 1:20,000 maps were digitized and converted to a GIS format. Digitizing of 1995 field data is in progress.

Analyses

Phase I

Stand-level root disease incidence was calculated as % infection by species. Incidence was mapped to identify variation across the landscape and highlight readily apparent hot spots. The influence of site factors other than species (e.g. age, site history) were not evaluated.

Phase II

Correlations between affected trees detected in air photo plots versus incidence of Armillaria detected in corresponding field plots were established for several stands.

Phase III

All information was mapped onto 1:20,000-scale forest cover maps. Ground truthing was conducted on an ongoing basis where and when required.

Phase IV

The reliability of the disease risk rating system depends on the survey methodology(ies) and survey intensity(ies) used for a given area. A reliability overlay will be constructed before the map is operationally used.

History/Time Table

Project started in 1991. Database updates occur on an annual basis as new information becomes available.

Status

Ongoing.

Brief Summary of Results

The goal of the database is to provide an inventory (at the polygon level) that can be used for a variety of purposes by resource managers such as planners and operational staff in silviculture, timber, planning, inventory landscape, and forest health.

Several different approaches to detection and mapping were employed to varying degrees of success. By far the most efficient appears to be the reconnaissance flights, which have enabled overview mapping. The cost per hectare was reduced dramatically with coverage increasing from 5 to 100% of polygons or silviculture openings. As a result, a base map has been completed which gives an overview of hot spots, trends in distribution, and a baseline for prioritization of activities such as detection. The reliability overlay will provide information on data reliability.

Because *Armillaria ostoyae* is at the most northern portion of its range in the Robson Valley District, one might expect to see the effects of landscape-level climate and site factors that may limit its distribution. An apparent trend in the distribution of *Armillaria ostoyae* has been observed. Occurrence of *Armillaria ostoyae* decreases with increasing elevation (it is generally absent above 1200 m). This elevation limit appears to be lower on the northeast aspects and higher on the southwest aspects (susceptible host species are present above 1200 m). It is hypothesized that critical minimum heat sums may play an important role in limiting the elevation range of *Armillaria ostoyae*. Because other factors could account for the observed trends, the above is a working hypothesis that needs testing.

Working Plans/Reports/Publications

All survey results are recorded in the History Record System (HRS). An undergraduate thesis report was produced based on the large scale aerial photography project; see footnote in summary.

Maps

Colour-themed Armillaria inventory maps for the Robson Valley District are available in digital or hardcopy format from the office of the Prince George Forest Region.

SUMMARY 31

Project
FRDA II Project: FC-FP-09

Resistance Mechanisms of Western Larch

Author(s)

R. Robinson, D. Morrison, and B. van der Kamp

Study Objectives

1. Confirm the apparent resistance of western larch to *Armillaria ostoyae.*
2. Determine the tree age at which resistance begins.
3. Characterize the nature of the resistance shown by western larch.

Overview

Layout and Treatments [29]

See Table 31-a for site descriptions.

Preliminary Investigation

Host Response. Two sites, with *Armillaria ostoyae*-infected western larch and Douglas-fir trees ranging in age from 5-35 years old, were identified in 1992, i.e. Eagle Bay and Phoenix Hill sites. A total of 50 infected and healthy root samples were collected from these sites to investigate host responses to *Armillaria* infection. Several infected roots from 90-year-old western larch trees, excavated in conjunction with a stumping trial at Bird Creek (see Summary 23), were also sampled.

Inoculation Techniques. Preliminary inoculation techniques were explored in field and greenhouse trials.

Inoculation Trials

Greenhouse Trials. Greenhouse trials were carried out at the FORCAN laboratory to demonstrate the infective ability of the various *Armillaria ostoyae* isolates and *Armillaria sinapina,* and to provide further material for microscopic examination.

In November 1992, 25 western larch seedlings were inoculated with *Armillaria ostoyae* (2 isolates, one with 10 replicates and one with 15 replicates) and 25 with *Armillaria sinapina* (2 isolates, one with 10 replicates and one with 15 replicates) following needle fall by replacing PVC piping with colonized oak blocks. In July 1993, a further 50 seedlings were inoculated with *Armillaria ostoyae* (using 5 isolates with 10 replicates each, plus 10 controls using uninfected oak blocks). The pots were arranged according to a randomized block design.

Field Trials. During May-June 1993, inoculation trials were established at Eagle Bay and Phoenix Hills. Further information on these trials, e.g. species, was unavailable.

Disease Monitoring

To monitor disease symptoms in young naturally regenerated trees (10-12 years old), two 10-m radius plots were established at the Eagle Bay site. Both plots were located in areas of high *Armillaria ostoyae* incidence. Information on other plot selection criteria was not provided. Plot 1 contained 15 Lw and 76 Fd seedlings, and Plot 2 contained 102 Lw and 22 Fd seedlings.

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[29] The final selection of subzones and sites will be made in consultation with Nelson Region and District personnel.

Protein Extraction

At Eagle Bay and Larch Hills, naturally regenerated trees, with and without *Armillaria ostoyae* infection, were selected for sampling. Five 10-year-old and five 27-year-old Lw trees were sampled at Eagle Bay. A similar number of Douglas-fir of the same age were sampled at Larch Hills. Sampling occurred in late April, early July, and late September. Protein extraction and examination of healthy and infected tissue from larch and Douglas-fir regeneration was conducted from April to November 1994. (Citation for the protein extraction procedure was not provided.)

Measures

Preliminary Investigation

Host Response. Host response to natural *Armillaria ostoyae* invasion was investigated by examining infected and non-infected root tissue microscopically for chemical and physical tissue responses, according to cryofixation techniques developed by Mullick and Jensen (1973). All infected root samples were sectioned longitudinally and examined microscopically to study their internal reactions to invasion.

Inoculation Trials

Inoculum was prepared using *Armillaria ostoyae* isolates collected from dead and dying Douglas-fir at several locations in BC. These isolates were collected from Coastal sites (Victoria, Shawnigan Lake) and Interior sites (Poplar Creek, Marl Creek, Robert Lake).

Oak branch wood was used as a substrate for the inoculum.

Greenhouse Trials. In the greenhouse trials seedlings were potted by placing PVC pipe vertically in the soil alongside the root system. Seedlings were inoculated by replacing PVC piping with colonized oak blocks.

Field Trials. In the field, roots were first carefully exposed. The oak inoculum block was placed against the bark, and the root and block were subsequently covered with mineral soil. Root diameters inoculated ranged from <1 to 10 cm. The inoculations were left and excavated in the fall of 1993 and again in the October 1994. Measured parameters were not outlined.

Disease Monitoring

All seedlings in each 10-m radius plot were monitored for chlorosis, leader growth reduction, presence or absence of resinosis at the base, and presence or absence of mycelial fans at the root collar. Each plot was monitored three times over a two-year period.

Protein Extraction

Bark and tissue samples were collected from healthy, abiotically wounded and infected tissue. Infected tissue was sampled either side of the periderm in front of the advancing infection. Healthy roots were abiotically wounded by freezing. Wounded tissue was sampled to monitor the trees non-specific response to wound repair.

Proteins were extracted from all samples. The total protein concentration was determined and the individual protein composition analyzed using SDS-PAGE technology.

A selection of these samples will be analyzed microscopically for chemical and physical tissue responses using cryofixation techniques developed by Mullick and Jensen (1973).

Analyses

Multivariate-analyses will be used to:

- Evaluate the relationship between tree resistance and response to infection to: distance of inoculum from root collar, root diameter, and tree age (inoculation trials).
- Evaluate whether there are any significant differences in protein profiles between Lw and Fd with respect to: time of year, and response to infection or wounding (protein analyses).
- Determine whether there are significant differences between Lw and Fd micrographs with respect to: infection, and age.

The combined results of the above analyses will provide information on the relationship between a particular response (i.e. type of periderm formed) to infection and the success of that reaction with respect to preventing or slowing down further advancement of the infection.

History/Time Table

1992	Sites for preliminary investigation identified and first samples collected.
	Field inoculation experiments and greenhouse trials initiated.
1993-94	Field inoculation experiments and greenhouse trials continued.
April 1994	Tentative project completion.

Status

Ongoing.

Brief Summary of Results

Preliminary Investigation

Host Response. Preliminary field investigations revealed several potential resistance mechanisms operating in western larch. Infections on the root systems of mature, vigorous trees were often stopped before reaching the vascular cambium by the formation of necrophylactic periderms. If periderm formation failed to prevent cambial infection, resinosis and callusing sometimes checked the fungus which was then confined by compartmentalization to woody tissues present at the time of infection. Adventitious roots that formed on the callused ends of the infected roots appeared to be protected from further infection by the compartmentalization process. In trees younger than 15 years, these responses did restrict the advance of the root disease. Further investigations will be undertaken to determine whether relationship between root size, tree age, and tolerance of western larch to *Armillaria os-*

toyae. The responses of infected Douglas-fir are currently being analyzed.

Inoculation Techniques. Inoculum blocks used in 1992 proved to be unsuitable as they failed to produce rhizomorphs. The technique for producing inoculum blocks was refined in 1993 allowing all subsequent inoculations to be performed with blocks actively producing rhizomorphs at the time of inoculation. Good colonization by Armillaria was achieved within two months on oak blocks measuring approximately 7 cm in diameter and 12 cm in length.

Inoculation Trials

Field Trials. The inoculation trials were ended in September 1994 when all inoculations were removed and examined. The results are being analyzed.

Greenhouse Trials. In September 1994 the inoculated seedlings were monitored for disease symptoms. These results are currently being analyzed.

Monitoring Disease

Initial analysis of the data shows a clear progression of disease in the young trees over the two-year period. Many trees showing symptoms at the beginning of the trial were killed well within the two-year period, even some trees apparently healthy at the start were killed within the two years. A more thorough analysis of the results is continuing.

Protein Analysis

Preliminary results from the protein samples reveal elevated protein levels in the tissues on the healthy side of periderms formed in advance of the fungus. Not all reaction types are impervious to the advancing Armillaria, because some profiles reveal specific fungal proteins in the tissues on the healthy side of these periderms. The elevated levels of protein in these tissues may be due to increased levels of host protein or to "leakage" of fungal enzymes through the periderm. Further analysis will determine which reaction types appear to be susceptible to "leakage". However, when comparing infected tissue to wounded tissue, there does appear to be an increase in certain proteins in response to fungal infection.

Working Plans/Reports/Publications

Mullick, D.B., and S.D. Jensen. 1973. Cryofixation reveals uniqueness of reddish-purple sequent periderm and equivalence between brown first and brown sequent periderms of three conifers. Can. J. of Bot. 51: 135-143.

Robinson, R. 1992. Evaluating the resistance of western larch to Armillaria root disease caused by *A. ostoyae*. Working Plan, FRDA II: FC-FP-09.

Robinson, R. 1992. Evaluating the resistance of western larch to Armillaria root disease caused by *A. ostoyae*. Third Quarter Progress Report (FRDA II project: FC FP-09).

Robinson, R. and D. Morrison. 1994. Resistance mechanisms of *Larix occidentalis* (western larch) to *Armillaria ostoyae*. Proceedings of the 8th International Conference on Root and Butt Rots. Wik, Sweden and Haikko, Finland. Aug. 9-16, 1993.

Maps

None.

Table 31-a. Site descriptions.

	Site							
	Phoenix Hills 1	Phoenix Hills 2	Phoenix Hills 3	Larch Hills	Eagle Bay1	Eagle Bay2	Eagle Bay3	Eagle Bay 4
Region	Nelson	Nelson	Nelson	Kamloops	Kamloops	Kamloops	Kamloops	Kamloops
District	Boundary	Boundary	Boundary	Salmon Arm	Salmon Arm	Salmon Arm	Salmon Arm	Salmon Arm
Opening No.	31	31	31	29	9	8	17	15
Plot Lat/Long								
Area (ha)								
Biogeoclimatic subzone	ICH mk1	ICH mk1	ICH mk1	ICH mw3	ICH mw3	ICH mw3	ICH mw3	ICH
Site Series	01/04	01/04	01/04	05	05	05	05	
Slope %								
Aspect								
Species composition/Age (years)/Site Class								
Stems/ha (no.)								
Terrain/Soil Class./ Soil Texture								
Disease/Insects	DRA	DRA	DRA	DRA	DRA	DRA	DRA	DRA
Stand History								
Plot Established								
Treatment								

See Appendix C for abbreviations.

SUMMARY 32

Project
Pest Control Project 29
(BCMOF 1990)

Root Disease Spacing Trial

Author(s) Schulting, J.

Study Objectives

1. Layout a trial and demonstration area to show the effects of spacing to different densities in young stands of Douglas-fir infected with root disease.

Overview

Layout and Treatments [30]

The two selected stands in the Merritt Forest District had a high root disease incidence and were suitable for juvenile spacing or thinning operations. The sites were sufficiently far apart (3.7 km) and were large enough for delineation of three treatment blocks. At each site three treatment blocks were established and the following treatments assigned:

- control (no spacing),
- spacing to normal standards, and
- spacing to normal standards plus removal of Armillaria-infected trees and any tree within a 1 m radius of infection sources.

Ten 5.64-m radius (100-m^2) plots were established per treatment block for a total of 60 plots. For each treatment block, five plots were established in areas with no root disease, and five plots established in areas containing at least one infected tree.

The treatments were undertaken in the winter of 1987-88. Trees >15-cm dbh or <2-m high were not removed unless infected. Douglas-fir was favoured over the other stand components.

Measurements

Pre-Treatment [31]

A root disease survey was conducted in each area to determine pre-treatment disease levels and location for each site. Data on tree growth, stocking, and infection status were collected on each plot. Stem maps were also produced. General information was recorded for the site and stand.

Post-Treatment

The establishment report recommended these post-treatment measures:

- Re-survey sample plots to map stems removed and stems remaining.
- Maintain each area and re-examine all plots regularly in order to assess

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[30] Information about how the plots were located, e.g. randomly or systematically, or about site characteristics was not provided in the Pest Control Project 29 summary (BCMOF 1990).

[31] Further information on sampling procedures and measures was not provided in the Pest Control Project 29 summary (BCMOF 1990).

post-treatment spread. This should be performed every one or two years.

History/Time Table

Summer 1987	Pre-harvest measures.
Winter 1988	Treatments undertaken.

Status

Unknown.

Brief Summary of Results

The initial survey determined that overall stocking was 1760 stems/ha in the first site and 3500 stems/ha in the second site, with density ranging from 5900 to 27,800 stems/ha. Armillaria root disease levels were measured as 14.6% at Site 1 and 7% at Site 2. Other pathogens were not present to any significant extent. Armillaria was diffuse in distribution to Site 1, with infection occurring mainly as single trees, and was aggregated into distinct infection centers at Site 2.

Contractor's Recommendations

- Re-survey sample plots to map stems removed and stems remaining after treatment
- Maintain each area and re-examine all plots regularly in order to assess post-treatment spread. This should be performed every one to two years.

BCMOF (1990) Comments

Results from this work should prove useful in determining the effects of thinning operations in Armillaria-infected stands. In addition, these sites will be useful demonstration areas for field crews. Suitable follow-up activities include:

- Regular monitoring and maintenance of all plots to ascertain disease spread after treatment.
- Perform on-site training for disease identification and appropriate control.

Working Plans/Reports/ Publications

Schulting, J. 1988. Spacing in *Armillaria obscura* infected stands in the Merritt Forest District. Contractor Report.12 pp plus stem maps.

Maps

None.

SUMMARY 33

Project **Mycoviruses for Biocontrol of Armillaria Root Disease**

Author(s) P. Spencer

Objectives

1. Examine *Armillaria ostoyae* isolates for presence of viral nucleic acids (double-stranded RNA (dsRNA)).
2. Determine the effects of dsRNA on growth and virulence of these isolates.
3. Characterize virus-like particles using electron microscopy and molecular techniques.

Overview

Layout and Treatments

Isolates of *Armillaria ostoyae* will be obtained from BC and other locations in North America and grown in liquid culture; nucleic acids will be extracted from the mycelium. Extracts will be examined for dsRNA.

Measurements

Mycelium of isolates with dsRNA will be examined with a transmission electron microscope and virus-like particles will be isolated.

Analyses

Virus-like particles will be characterized using electron micrographs.

Status Ongoing.

History/Time Table

June 1992	Project initiated and first sample isolates obtained.
December 1992	First indication of dsRNA in isolates.
June 1993	First electron micrographs of virus in isolate.

Brief Summary of Results

One confirmed and six suspected dsRNA isolates are identified. Preliminary characterization of virus-like particles in one isolate is complete. Virulence tests are set up, and transmission electron microscope studies are ongoing.

Working Plans/Reports/ Publications

Spencer, P., J.S. Sutherland, and E. White. In prep. Isolation and characterization of a mycovirus from *Armillaria ostoyae.*

Spencer, P., Sutherland, J.S. and White, E. In prep. A survey of double stranded RNA elements in Armillaria.

Maps None.

SUMMARY 34

Project EP 1187

Nesting Habitat Selection by Red-Breasted Nuthatches and the Role of Forest Health Agents

Author(s) C. Steeger, M. Machmer, and C. Hitchcock

Objectives

1. Characterize nest tree features and nest site features of active red-breasted nuthatches.

2. Evaluate the red-breasted nuthatch's preferences for certain nest tree features and nest site features, relative to the features of randomly chosen trees.

3. Examine potential interrelationships among various forest health agents and the red-breasted nuthatch's nesting preferences.

Overview

This study is a subset of a broader research program investigating wildlife trees and their use by cavity nesters in selected stands of the Nelson Forest Region (Steeger et al. 1993; Steeger and Machmer 1995; Machmer and Steeger 1995).

Layout and Treatments

See Table 34-a for site description.

Four blocks, scheduled for harvest in winter 1996, and an adjacent control were systematically sampled for wildlife trees and active cavity nests. Wildlife trees were sampled in summer of 1994 and nest searches were conducted from May to July of 1994 and 1995.

Measurements

Surveys of Wildlife Trees

A wildlife tree was defined as a coniferous or deciduous tree >10-cm dbh and either: dead; live but defective; or live, healthy, and showing evidence of use for nesting or foraging by cavity nesting birds. Wildlife trees were assessed on 0.04-ha plots (11.28-m radius) arranged on a uniform grid spaced 100-m apart throughout each study block. One plot/ha (i.e. 4% of the total area) was sampled. The following variables were measured within each plot: total number, dbh (cm), height (m), sapwood condition (hard, spongy, soft), heartwood condition (hard, spongy, soft, powdery), number of live and dead trees >10-cm dbh, number of nesting and feeding cavities per wildlife tree, number of trees with broken tops or trunks, number of trees with Armillaria root disease, number of trees with stem rot, number of trees with dwarf mistletoe, and number of trees attacked by mountain pine beetle.

Presence of Armillaria root disease was visually determined on the basis of above-ground symptoms (e.g. thin chlorotic foliage, resinosis, and exposed mycelial fans) and root assessment. Stem rot was inferred from visible conks or by taking increment cores at breast height. Visible brooms were considered symptomatic of dwarf mistletoe, and characteristic pitch tubes, galleries, or adult exit holes were used to confirm mountain pine beetle attack.

Active Nest Surveys

Nest surveys were conducted along transect lines spaced 100-m apart throughout the study blocks. A nest was considered active if parents were observed entering the cavity to incubate or feed young. Nest trees were assessed with respect to: wildlife species occupancy, tree species, dbh, and height, sapwood and heartwood condition, nest cavity height, number of nesting and feeding cavities, broken tops or trunk, presence of Armillaria root disease stem rot, dwarf mistletoe, and mountain pine beetle.

One 11.28-m radius nest tree plot was centered on each active nest tree and all trees >10-cm dbh in nest tree plots were assessed for the same variables examined in random wildlife tree plots (see above). Aspect (°), slope (%), and number of vegetation strata (Luttmerdig et al. 1990) were also determined for nest tree plots.

Analyses

Multiple logistic regression was used to test for preferences in nest tree characteristics used by red-breasted nuthatches. Analyses were performed at increasing scales (i.e. preference for individual tree characteristics, nest plot characteristics, and block-level characteristics). Individual trees that were used for nesting were compared to unused trees in nest plots. At the plot level, random plot variables were summarized using principal components analysis, and nest and random plot scores were compared using t-tests. At the block level, densities of active nests in blocks with varying levels of Armillaria root disease were compared using correlational analysis.

Status

Ongoing.

History/Time Table

Summer 1994	Pre-harvest wildlife tree and active nest surveys.
Summer 1995	Pre-harvest active nest surveys.
Fall 1995	Data analysis and publication preparation.

Brief Summary of Results

A total of 58 red-breasted nuthatch nests were located. Site features were characterized for all 58 red-breasted nuthatch nests, and for 85 random plots.

Tree-Level Comparisons

Red-breasted nuthatches preferred to nest in dead trees with broken tops. Douglas-fir, paper birch, and western larch were preferred nest tree species. Taller, larger diameter trees than those available in nest plots were used for nesting. Trees infected with Armillaria root disease and with visible conks indicative of stem rot were preferred, and trees with dwarf mistletoe were avoided. No nests were found in dead lodgepole pine trees attacked by mountain pine beetle. Trees with spongy to soft sapwood and heartwood condition were also preferred for nesting. All of the above variables were significant at the P=0.05 level.

Plot-Level Comparisons

Red-breasted Nuthatches preferred to nest in relatively flat, open habitat with large, dead, broken-top trees that tended to have stem rot. Nest plots did not differ from random plots in the number of trees infected with Armillaria, likely because the root disease is very widespread throughout the entire stand.

Block-Level Comparisons

At this scale of comparison, the density of active red-breasted nuthatch nests and the density of trees infected with Armillaria root disease were strongly correlated ($r^2 = 0.753$; $P = 0.0564$), as was the density of nuthatch nest trees and the density of dead trees ($r^2 = 0.77$; $P = 0.05$). As expected, there was a strong correlation between the density of Armillaria-infected trees and the density of dead trees on blocks ($r^2 = 0.87$; $P < 0.05$).

The authors conclude that Armillaria root disease plays an important role in creating wildlife tree habitat. They suggest that the preference for Armillaria-infected trees arises as a result of their greater susceptibility to stem rot. Stem rot softens heartwood and sapwood, thereby facilitating cavity excavation which is particularly important for weak cavity excavators such as nuthatches and chickadees. The authors note that their data set does not allow them to conclusively distinguish between preference for Armillaria-infected trees per se, or simply for dead trees.

Working Plans/Reports/ Publications

Steeger, C. and M. H. Machmer. 1995. Wildlife trees and their use by cavity nesters in selected stands of the Nelson Forest Region. Forest Sciences Section, Nelson Forest Region, BCMOF. Tech. Rep. TR-010. 28pp.

Maps

See above report.

Table 34-a. Site description.

	Site
	Deer Creek
Region	Nelson
District	Arrow Lake
Opening No.	
Plot Lat/Long	49°27'N 118°15'W
Area (ha)	52
Biogeoclimatic Subzone/Site Series	ICHdw /01a, 01b, 02, 03
Slope (%)	0 - 44
Aspect	S to SW
Species Comp./Age/Site Class	$Fd_5Pl_3Lw_1$(CwHwPyAtEp)/80/x
Stems/ha (no.)	476
Terrain/Soil Class./Soil Texture	x/x/Sil
Diseases/Insects	DRA
Stand History	fire
Study Establishment	1994
Treatment(s)	N/A

See Appendix C for abbreviations.

SUMMARY 35

Project

A Comparison of Patch Clearcut Silvicultural Systems Using Conventional Harvesting and Post-Harvest Stumping for Armillaria Root Rot Infected Stands

Author(s)

C. Thompson

Study Objective

1. Assess the feasibility of using stump removal in small patch cuts to reduce the infection levels of Armillaria root disease.

2. Compare the early performance of three species and their relative susceptibility to Armillaria root disease after stump removal in small patch cuts.

Overview

Layout and Treatments

See Table 35-a for site description.

The area was stratified into nine site series. Harvest blocks were designed after stratification.

Two of the harvest blocks were split in half. The whole area was conventionally harvested and one half was stumped post-harvest using a EX 270 LC excavator with live thumb. One unharvested control plot was established between the harvested openings. In the spring of 1994, each harvested opening was planted with an intimate mixture of western larch, paper birch, and Interior Douglas-fir in alternate rows at a density of 1200 stems/ha, without regard for harvesting treatment.

Pre-harvest ecological site analysis was completed using systematically spaced, nested 1.99-m and 3.99-m radius plots. Plots were located at 30-m intervals along 13 transects spaced 30-m apart.

Measurements

Pre-Harvest

Biogeoclimatic site series, slope, aspect, and site degradation sensitivity were determined for each treatment plot. The following measurements were also taken in each plot:

Competing Vegetation. Percent cover of herbs in each quadrant of 1.99-m vegetation plots was measured. Average height was estimated for each species, and cover and height values were averaged to obtain a single value for each plot. A modification of the line intercept method was used to measure percent cover and average species height for shrubs. Cover values for herbs and shrubs will be converted to area, and volume will be calculated as average species height multiplied by area.

Conifer Regeneration. Measurements taken in 3.99-m radius regeneration plots for all stems <12.4-cm dbh and >1.3-m height included: total number of trees, species, average height by species, average height by leader species, average age by species, and condition/vigour (classified as good, medium, poor).

Root Disease. Root disease infection centers were mapped by establishing survey lines at 50-m intervals across the proposed harvesting area. Infection centers were located by their position on these lines, and by running secondary survey lines perpendicular to the primary lines to identify the boundaries of each center. Information on health codes was not provided.

Post-Harvest

Post-harvest assessments will include the following:

Soils. Following harvest, a post-harvest soil disturbance survey will be undertaken in harvested treatments following Curran and Thompson (1990).

Regeneration. Post-harvest measurement of conifer regeneration will be conducted in the first, second, third and fifth growing seasons following harvest, using permanent 50m^2 plots located systematically through each treatment unit. Measures will include current height, crown level diameters, leader length, crown length and width, condition, nature of damage, and cause of mortality.

Armillaria. Armillaria infection will be assessed on all trees within the 50-m^2 or 3.99-m plot at each seedling measurement as part of the above assessment. To capture this information, assessments will also be conducted in Years 10, 15, and 20.

Analyses

ANOVA will be used to compare conifer regeneration variables between treatments. Armillaria recurrence will be tested by either ANOVA or Chi square.

Status

Ongoing.

History/Time Table

1992	Plot layout and pre-harvest site analysis.
1993	Harvest.
1994	Planting and assessment report.
	First growing season post-harvest measurements.
1995	Second growing season post-harvest measurements.
1996	Third growing season post-harvest measurements.
1998	Fifth growing season post-harvest measurements.

Brief Summary of Results

A full assessment was conducted in 1995; results are being analyzed.

Working Plans/Reports/ Publications

J.M.J. Holdings Inc. 1992. Wetask Lake silviculture systems demonstration forest establishment report. Revelstoke Forest District, BCMOF.

Maps See following.

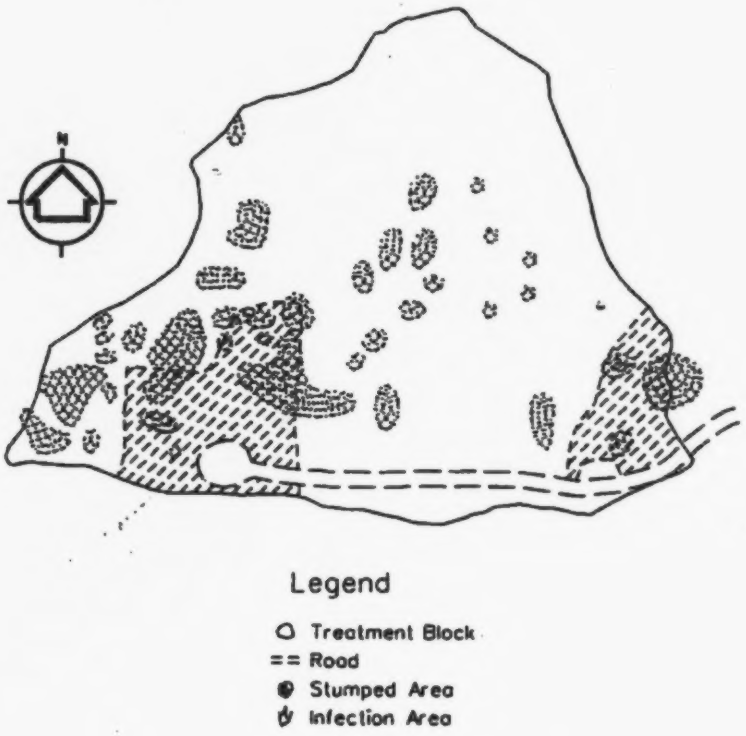
Table 35-a. Site description.

	Site
	Wetask Lake
Region	Nelson
District	Revelstoke
Opening No.	82L099-038
Plot Lat/Long	52°85'N 118°22'W
Area (ha)	11.8
Biogeoclimatic Subzone	ICHmw3
Site Series	01-06
Slope (%)	10-30
Aspect	S-SE
Species Comp./Age (y)/Site Class	OS: FBi(Pw)/ age class 4/G
	PL:N/A
Stems/ha (no.)	OS: 976-1426
	PL: 1200
Terrain/Soil Class./Soil Texture	GF terrace/x/x
Disease/Insect	DRA
Stand History	
Study Establishment	1992
Treatment(s)	1. Post-harvest stumping
	2. Conventional harvesting
	3. Unharvested control

See Appendix C for abbreviations.

WETASK LAKE

SCALE: 1:5000


N
Legend
○ Treatment Block
== Road
● Stumped Area
▨ Infection Area

SUMMARY 36

Project
Pest Control Project 53

Knappen Creek Armillaria Control Trial: Area Survey and Layout

Author(s)

T.M. Thompson and Associates Ltd.

Study Objectives

1. Perform a line intercept/Armillaria regeneration survey to map all infection centers.

2. Lay out the area for treatments.

3. Provide a detailed map and brief report including treatment recommendations.

Overview

Layout and Treatments

A line intercept/*Armillaria* regeneration survey was performed on a 51.1-ha site near Knappen Creek, Boundary TSA, to determine infection levels, layout the site for treatment and map all infection centers.

The area was surveyed using techniques from Pest Control Project 34 (BCMOF 1990). Survey intensity consisted of strips spaced at 50-m and plots spaced at 100 m along all strips. Disease incidence was recorded within and between plots. Infected spots were verified for Armillaria within plots, and the start and end points of all infection centers were mapped along the transects.

Stumping operations were conducted on this site in November, 1989, using a feller-buncher equipped with a thumb and claw attachment.

Measurements

Pre-Treatment

The treatment was thoroughly covered and mapped. Disease incidence was measured in the same manner as in Summary 16. Data on topography, access, soils, and timber type were also obtained.

Post-Treatment

A time and motion study was undertaken; see Summary 16. Documentation on other field measures was unavailable.

History/Time Table

October to November 1988. Pre-harvest Armillaria survey.

Status

Complete.

Brief Summary of Results

Armillaria root disease was found throughout the site. Disease levels were estimated as 26.2% within plots and 13.3% between plots. This discrepancy between figures was probably caused by the occurrence of missed (non-symptomatic) trees along transect lines. However, mapping along each transect was considered useful for locating major infection centers for future treatment. Thus, the modified survey method was judged as very practical. Many small one-to-three tree centers were noted but all major infection centers were mapped. Selective logging was considered to have exacerbated the problem. No other damaging agents were noted.

Contractor's Recommendations

- Control Armillaria root disease on the site by uprooting stumps to remove and expose the pathogen.
- Treat the site with an excavator, because slopes are gentle and soils are deep and coarse-textured.
- Any treatment method employed should avoid soil erosion due to the proximity of the creek.

BCMOF (1990) Comments

Follow-up activities suitable under FRDA II include:

- Regular monitoring of the site to assess treatment effectiveness and degree of site disturbance.
- Performance of the survey and treatment methods conducted during this project on additional sites for thorough evaluation.

Working Plans/Reports/Publications

None.

Maps

None.

SUMMARY 37

Project **Armillaria Management in the IDF by Bridge Tree Spacing**

Author(s) B.J. van der Kamp

Study Objectives In the IDF:

1. Evaluate whether the distribution of Armillaria infection is clumped, and if so, the size of the clumps.

2. Evaluate whether Armillaria infection is associated with old stumps.

3. Evaluate the efficacy of bridge tree removal as a technique to control or reduce the spread of Armillaria.

Overview

Layout and Treatments

See Table 37-a for site description.

The study area was chosen based on uniformity of site characteristics, Armillaria distribution and intensity, and site history. The area was logged to a diameter limit in 1963. The pre-treatment stand included tall residuals, advanced regeneration, and trees established since logging.

Nine 40x40 m plots, separated by 10-m boundaries, were established in the infected area. Three replicates of three treatments each were randomly assigned to the plots. The treatments were:

Bridge tree spacing	Symptomless trees within 3 m of dead or symptomatic trees were felled. Remaining clumps of symptomless trees (>3) were spaced to a minimum distance of 1 m. Large groups of residual trees (>5) were thinned based on operational standards for juvenile spacing.
Operat. juvenile spacing	Operational juvenile spacing was conducted. Crop trees were defined as follows: tallest conifers of good form and vigour; free from injury or disease; and species preference as: Douglas-fir, lodgepole pine, and spruce. Depending upon species, spacing was either 2.5 or 2.8 m.
Controls	No treatment applied.

Measurements

Pre-treatment plot measurements were as follows:

- All live and dead trees >0.5-m high not occurring in small clumps: species, dbh for trees >3-m high, height for trees <3-m high, location (distance north and east from SW corner of each plot), and disease symptom code.

- All healthy trees of the same species >0.5-m and <3-m high occurring in small clumps (<4-m diameter): species, number of trees, average diameter of group of trees, location of the center of the group, and disease symptom code.
- All stumps and old snags: species and diameter.

(In cases where clumps contained diseased or dead trees, all trees were individually measured.)

Tree health codes were defined as follows:

Health Code 1 = Healthy

Health Code 2 = *Armillaria ostoyae* mycelial fans and basal resinosis present but no crown symptoms

Health Code 3 = *Armillaria ostoyae* mycelial fans and basal resinosis as well as crown symptoms such as chlorosis and thinning

Health Code 4 = Dead, with symptoms of *Armillaria ostoyae* on the lower side

Health Code 5 = Dead, with no symptoms of *Armillaria ostoyae*

Post-treatment, all trees removed by treatment will be recorded. Every fifth tree will be marked with a numbered tag to facilitate relocation during remeasurements. Future measurements will include disease symptom codes for all trees, tree clumps, and spaced stumps.

Analyses

Pre-treatment stem maps were generated. The following stand descriptions were calculated: number of stems, and stumps and snags per hectare by species and disease code. Of the 6511 trees in the nine plots combined, 663 were symptomatic.

Spatial Analysis by Variance-Over-Mean Ratios

A series of square grids with grid sizes ranging from 1 to 20 m^2 (1-m intervals) were systematically superimposed on each plot. The number of stumps, trees (live and dead), and Armillaria-infected and -killed trees in each square were counted. The mean and variance for the number of items (stumps, trees, and diseased trees) per grid square and grid size were calculated for all nine plots combined. For each grid size, variance-over-mean ratios (var/mean) were tested for significance from unity. Also, the number of grid squares with 1, 2, 3, etc. trees (or stumps or diseased trees) was compared to the number predicted by a Poisson distribution with a mean equal to the average number of items per grid square, using a Chi-square test (χ^2).

To simulate a spatially random distribution of Armillaria, var/mean ratios were calculated by randomly selecting 663 trees from among the 6511 trees in the nine plots, treating these randomly selected trees as "diseased" trees, and then repeating the grid square count. The simulated ratios were compared to those observed for the actual diseased trees using χ^2 tests.

Diseased Tree Group Size

The distance from each diseased tree to all trees within 11 m of that diseased tree was calculated. The average percentage of trees infected was then calculated for 1-m wide bands surrounding each diseased tree.

A diseased tree was considered to belong to a particular group if it was less than a critical distance from at least one other diseased tree belonging to that group. The number of diseased groups and the number of trees belonging to each group were determined for critical distances of 2, 3, 4, and 5 m. The proportion of diseased trees that were still alive was calculated for each group size.

Stump and Armillaria Root Disease

The distance from each healthy and infected tree to the nearest stump was determined. The proportion of all trees infected by Armillaria was then calculated for 1-m wide bands around each stump. The product of the overall incidence and the total number of trees within each 1-m band were used to simulate a uniform distribution of disease incidence with increasing distance from each stump. The predicted and observed number of infected trees in each band were compared using χ^2 tests.

In addition, the proportion of trees infected in each stump domain (defined by the perpendiculars drawn to the midpoints of lines joining adjacent stumps) was calculated. χ^2 tests were used to compare observed frequency of stump domains by disease incidence and two predicted frequency distributions: random distribution of diseased trees versus observed, and random distribution of stumps versus observed.

Area Affected by Armillaria Inoculum

Within each plot, the percent of the area greater than a set of critical distances (ranging from 2.0 to 7.0 m in 0.5-m steps) from the nearest infected tree was calculated. For each plot, 200 randomly located points were chosen, and the number of the points greater than the critical distance from the nearest diseased tree was recorded and averaged for the nine plots. The proportions were used as estimates of the non-infected area for each critical distance. Conversely, this proportion subtracted from unity equalled the "unstocked" area given a rule such as the "3-m rule": "No tree within x(3) m of a diseased tree shall be considered free to grow".

History/Time Table

May-July 191993	Plot location and stem mapping.
October 1993	Spacing treatments.
Summer 1995	First re-measurements, further re-measurement every five years.

Status

Ongoing.

Brief Summary of Results

General

The incidence of Armillaria-symptomatic conifers on individual plots ranged from 6.8 to 16.5% (overall 10.2%). The report attributed the marked increase in incidence of infection with tree size to the fact that large trees were both older and had larger root systems than younger, smaller trees, and were therefore more likely to have contacted Armillaria inoculum.

Spatial Analysis by Variance-Over-Mean Ratios

The var/mean ratios indicated that stumps were randomly distributed with the experimental area, while all trees and diseased trees were clumped. An increase var/mean ratio for all trees between grid sizes 1 to 14 m indicated a hierarchy of tree clump sizes in the experimental area ranging from about 1 to approximately 100 m^2 in size.

Two hypotheses were presented to explain the apparent clumping of Armillaria-infected trees:

1. Armillaria-infected trees are restricted to spatial domains defined by the presence of active inoculum, and/or
2. All trees might be within the infection range of active inoculum.

A χ^2 test comparing the observed and predicted (assumption: spatially random distribution of Armillaria) distribution of infected trees resulted in significantly greater observed var/mean ratios than the predicted ratios for grid sizes ≤9 m, but not for grid sizes >9 m. This formed the basis for rejecting the second hypothesis that all trees were equally exposed to Armillaria inoculum and therefore had an equal probability of infection.

Diseased Tree Group Size

Active Armillaria centers were small; approximately 4-6-m in diameter. The incidence of diseased trees at distances >4-m distance from a diseased tree was very nearly equal to the overall incidence. On average, the 4-m radius circle around each infected tree contained 6.23 and 22.36 diseased and healthy trees, respectively.

For the 3-m critical distance, 206 infection groups were calculated within the 1.44-ha study area, 47% of which consisted of single diseased trees (symptomatic and/or dead). Fifty-six percent of the diseased trees were members of groups with more than four diseased trees.

A χ^2 test comparing the observed and predicted (assumption: the proportion of symptomatic trees is the same for all group sizes) disease incidence per critical distance was significant, indicating high variation; but, no obvious pattern related to center size was detected.

Nineteen percent of single-tree groups consisted of a symptomatic living tree. Assuming that many of these trees were symptomless several years ago, the report concluded that full expression of underground Armillaria inoculum may take up to or more than 30 years after the last disturbance.

Stumps and Armillaria Root Disease

Infection incidence within stump domains varied from 0 to 100%. A relatively low rate of infection was found among trees within 1 m of stumps. Correlation between percent of trees infected and distance from stumps was not significant. The χ^2 comparison of the observed vs the predicted (uniform distribution) number of diseased trees per band width was not significant.

The report concluded that in the experimental area, 30 years after logging, the probability of Armillaria infection was related neither to the distance to the nearest stump nor to the initial inoculum potential of the stump domain in which the tree occurs. Further, the report indicated that decline of infection incidence with distance from stumps that is sometimes observed within a decade or so of regeneration may be a temporary phenomenon that has little bearing on the probability that trees will reach maturity.

Area Affected by Armillaria Inoculum

The optimum distance between diseased trees and crop trees in bridge tree removal spacing will be a compromise between the probability of successfully isolating crop trees from current inoculum sources and the unstocked area created in doing so. Over time the treatment trial will yield information on the optimum distance to minimize unstocked areas.

Working Plans/Reports/ Publications

van der Kamp, B.J. 1994. The spatial distribution of Armillaria root disease in an uneven-aged, spatially clumped Douglas-fir stand. Can. J. For. Res.

Contract with Protection, Cariboo District, Ministry of Forests (18815-20; PM033; 102559).

Maps

See following.

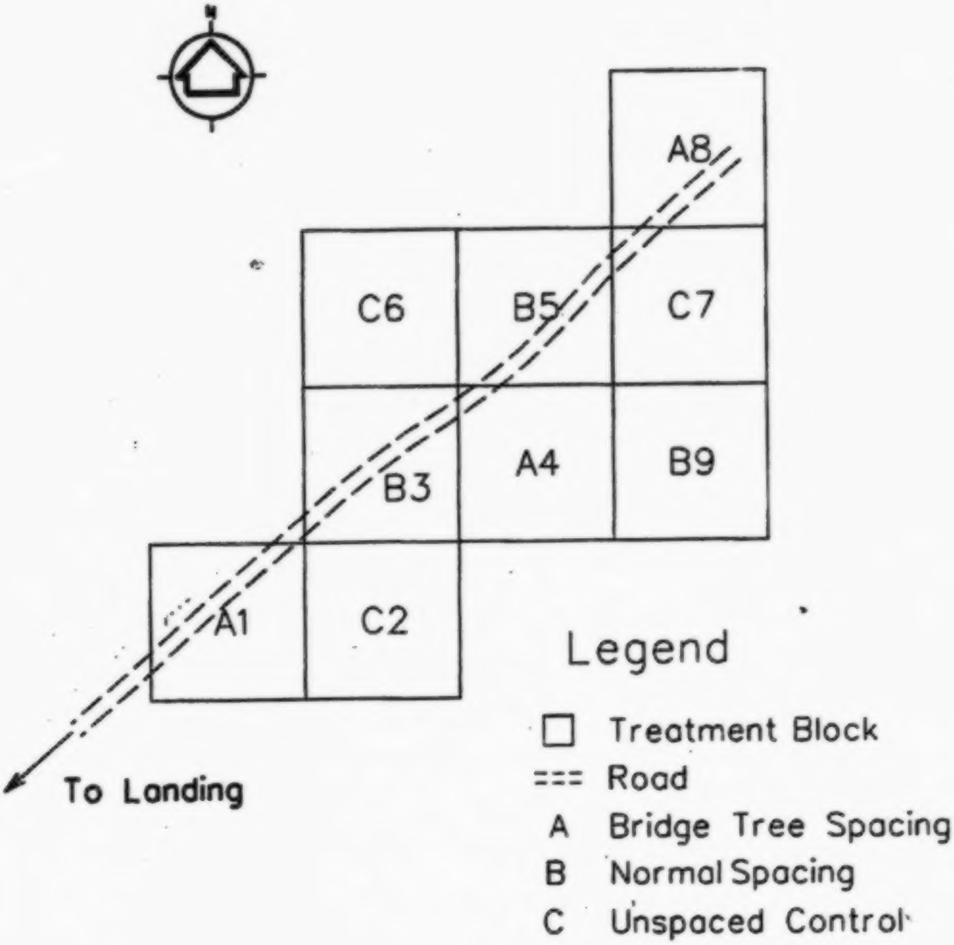
Table 37-a. Site description.

	Site
	Knife Creek, Alex Fraser Research Forest
Region	Cariboo
District	100 Mile House
Opening No.	93A 001-14
Plot Lat/Long	52°03'N/ 121°50'W
Area (ha)	1.4
Biogeoclimatic Subzone	IDF dk
Site Series	03/04
Slope (%)	flat
Aspect	NA
Species Composition/Age(y)/Site Class	OS: F(Pl)/x /M PL: x
Total Stems/ha (no.)	OS: 4861 (2900-8100) PL:x
Terrain/ Soil Class./Soil Texture	x/x/x
Diseases/Insects	DRA
Stand History	diameter limit cut 1963
Study Establishment	1993
Treatments	1. bridge tree spacing
	2. operational juvenile spacing
	3. unspaced control

See Appendix C for abbreviations.

KNIFE CREEK

SCALE: 1:2000


N
A8
C6
B5
C7
B3
A4
B9
A1
C2
To Landing
Legend
☐ Treatment Block
=== Road
A Bridge Tree Spacing
B Normal Spacing
C Unspaced Control

SUMMARY 38

Project
FRDA II FC-FP-024

Rate of Spread of *Armillaria ostoyae* in the Central Interior of British Columbia (Pre-Treatment)

Author(s)

B.J. van der Kamp

Study Objectives

1. Estimate the rate of spread of *Armillaria ostoyae* in active disease centers within a three-year period.

Overview

Layout and Treatments

See Table 38-a for site description.

The study area was chosen based on uniformity of site characteristics, *Armillaria* distribution and intensity, and site history. The periphery of a 25-ha Armillaria center was delineated based on presence/absence (lower bole mycelial fans) of *Armillaria ostoyae* in individual trees to either side of the line. A total of 645 m of periphery was permanently marked into 50 m, or slightly less than 50 m, sections. A 15-m strip on either side of the center's edge was also permanently marked.

Measurements

Within the 30-m strip, all trees >15-cm dbh were classified into one of the following health codes:

Health Code 1 = Healthy

Health Code 2 = *Armillaria ostoyae* mycelial fans and basal resinosis present but no crown symptoms

Health Code 3 = *Armillaria ostoyae* mycelial fans and basal resinosis as well as crown symptoms such as chlorosis and thinning

Health Code 4 = Dead, with symptoms of *Armillaria ostoyae* on the lower bole

Health Code 5 = Dead, with no symptoms of *Armillaria ostoyae*

Other information recorded included dbh and tree location (distance along and from the line). Symptoms were recorded in 1989 and 1992.

Isolates from seven different locations along the 645-m center edge were collected. Isolates were grown in petri dishes to observe growth patterns.

Analyses

Rate of Armillaria spread for three stages of symptom development was evaluated:

- Initial infection: healthy to diseased (Class 1 to Classes 2-4).
- Advance of infection: increased symptoms (Class 2 to Classes 3, 4).
- Mortality: diseased with symptoms to dead (Classes 2-3 to Class 4).

An average surface area occupied by each tree was estimated from stand density in the non-diseased 15-m strip (645x15-m / 405 trees = 23.9

m^2/tree). The average rate of spread for each stage over the three years was calculated based on the number of trees that changed in status (i.e. disease class) within the 30-m strip multiplied by the average surface area per tree and divided by the length of survey line. This calculation assumes the rate of spread is constant regardless of tree age.

The length of time from appearance of the first above-ground symptoms of *Armillaria ostoyae* to death was also calculated based on the assumption that the number of trees in each symptom class was constant. Average residence time in symptom classes 2 and 3 was calculated as the average number of trees in each class in 1989 and 1992 divided by the average number of trees that changed between any two symptom classes over the three-year period.

History/Time Table

1989	Plot layout, first measurements.
1992	Final measurements.
1992	All harvest.
1993	Established a demonstration area for stump removal and alternative conifer and hardwood species for control of *Armillaria ostoyae* (see Summary 43).

Status

Complete.

Brief Summary of Results

The report concluded that the entire edge of the Armillaria center originated from a single *Armillaria ostoyae* mycelium because the sampled isolates grew together without distinct boundaries. Variation in pathogenicity among isolates along the periphery of the center was therefore not considered.

The average rate of *Armillaria ostoyae* spread per 50-m section was 0.22 m/y (SD: 0.161; n=13). It was also calculated that, on average, six years was required from the time the first above-ground symptoms appeared until death.

The report summarizes the limitations of extrapolating the above study results to other sites as follows:

- short study time frame, which does not permit quantification of long term sources of variation (e.g. climate changes),
- single isolate,
- single site series, and
- northern extent of the distribution of Armillaria.

Based on the relatively low rate of spread calculated, compared to that reported elsewhere in the literature, the report states that it may be necessary to use local and site-specific measures of rate of spread when predicting disease development.

Working Plans/Reports/Publications

van der Kamp, B. 1993. Rate of spread of *Armillaria ostoyae* in the central interior of British Columbia. Can. J. For. Res. 23: 1239-1241.

N/A. See Summary 39.

Table 38-a. Site description.

	Site
	Gavin Lake
Region	Cariboo
District	Williams Lake
Opening No.	93A 042-366
Plot Lat/Long	52°27'N/ 121°49'W
Area (ha)	25
Biogeoclimatic Subzone	SBSmh
Site Series	03/04
Slope (%)	Gentle
Aspect	S
Species Composition/ Age(y)/Site Class	OS & PL: F(PlSBiCt)/110/x
Total Stems/ha (no.)	OS & PL: 418
Terrain/ Soil Class./ Soil Texture	x/x/SL
Diseases/Insects	DRA
Stand History	Natural fire
Study Establishment	1989
Treatments	None

SUMMARY 39

Project
FRDA II PC-FP-024

Measurement of *Armillaria ostoyae* in the Central Interior of British Columbia by Inoculum Removal and Use of Alternate Species

Author(s)

B.J. van der Kamp

Study Objectives

1. Determine efficacy of stump removal for the control of *Armillaria ostoyae*.

2. Determine relative resistance of several common and (possible) silviculturally acceptable conifer and hardwood species to *Armillaria ostoyae* following conventional harvesting.

Overview

Layout and Treatments

See Table 39-a for site description.

The peripheral edge of a 25-ha Armillaria center was delineated. Following clearcut harvesting, 21-25-m wide plots were installed such that the plots straddled the edge of the Armillaria center (≅50 m either side).

Stump removal and Species Trial

Two sets of four adjacent plots were randomly selected for the stumping trial. In each of the four plots the two inner plots were stumped by excavator. Stumps were left on the site, inverted in stump holes. Two replicates of a Douglas-fir and lodgepole pine species trial were randomly assigned to the stumped and non-stumped plots.

Alternative Species Trial

Two replicates of five alternative species trials (larch, spruce, aspen, birch, and cottonwood) were randomly assigned to the remaining ten plots. In addition, three plots of 25x50-m were planted with aspen, birch, and cottonwood.

Except for the four stumped plots, all plots were disk trenched. Seedlings were planted at 2x2-m spacing in 1993. In 1994, plots were fill planted, naturals removed, and brush control undertaken as required. Additional fill planting was expected to be required in 1995.

Measurements

Pre-harvest, the following information was collected within 15 m of each side of the center edge for all trees and stumps: species, x and y co-ordinates (distance along and from the base line), and disease status (refer to table in Summary 37).

Initial post-harvest measurements (1994) on all stumps within 15-m of the center edge will include: species, x and y co-ordinates (30-m buffering edge only), and disease status.

Disease status will be monitored 5, 10, 15, and 20 years after planting on all seedlings. After 15 years of age, assessments will also include tree dbh and height.

Analyses

Analyses will include:

- Descriptive summaries of survival (%); and Armillaria infection by species, plot, and treatment.
- Detailed spatial analyses to evaluate *Armillaria* distribution; and spread of Armillaria from stumps to seedlings, and from seedling to seedling.
- ANOVA to test differences by species and treatment.
- ANOVA to test species by activity zone interactions within the 25x150-m plot: old (infected zone to the inside of the 15-m strip), active (30-m strip), and healthy (non-infected area outside the 15-m strip).

Brief Summary of Results

Armillaria ostoyae is the major pathogen causing tree mortality in 100-year old trees at this research site. Within two years of harvest, Armillaria rapidly invaded stumps of trees with latent infections on their root system (i.e. no above-ground symptoms). Further results are pending.

History/Time Table

1989-90	Survey and completion of research plan.
1992	Re-measurement of edge tree disease status harvested; stump removal.
1993	Planted.
1994	Stump inspection, regeneration survey, and fill-in planting.
1995	Final stump inspection.
1996	First disease assessment survey, brush control.

Status

Ongoing.

Working Plans/Reports/ Publications

van der Kamp, B. J. 1989. Armillaria in the Alex Fraser Research Forests: A proposal for a research and demonstration project. Department of Forest Sciences, UBC. Vancouver.

———. 1990. Armillaria in the Alex Fraser Research Forest: progress report and research plan. Department of Forest Sciences, UBC. Vancouver.

———. 1993. Rate of spread of *Armillaria ostoyae* in the central interior of British Columbia. Can. J. For. Res. 23:1239-1241.

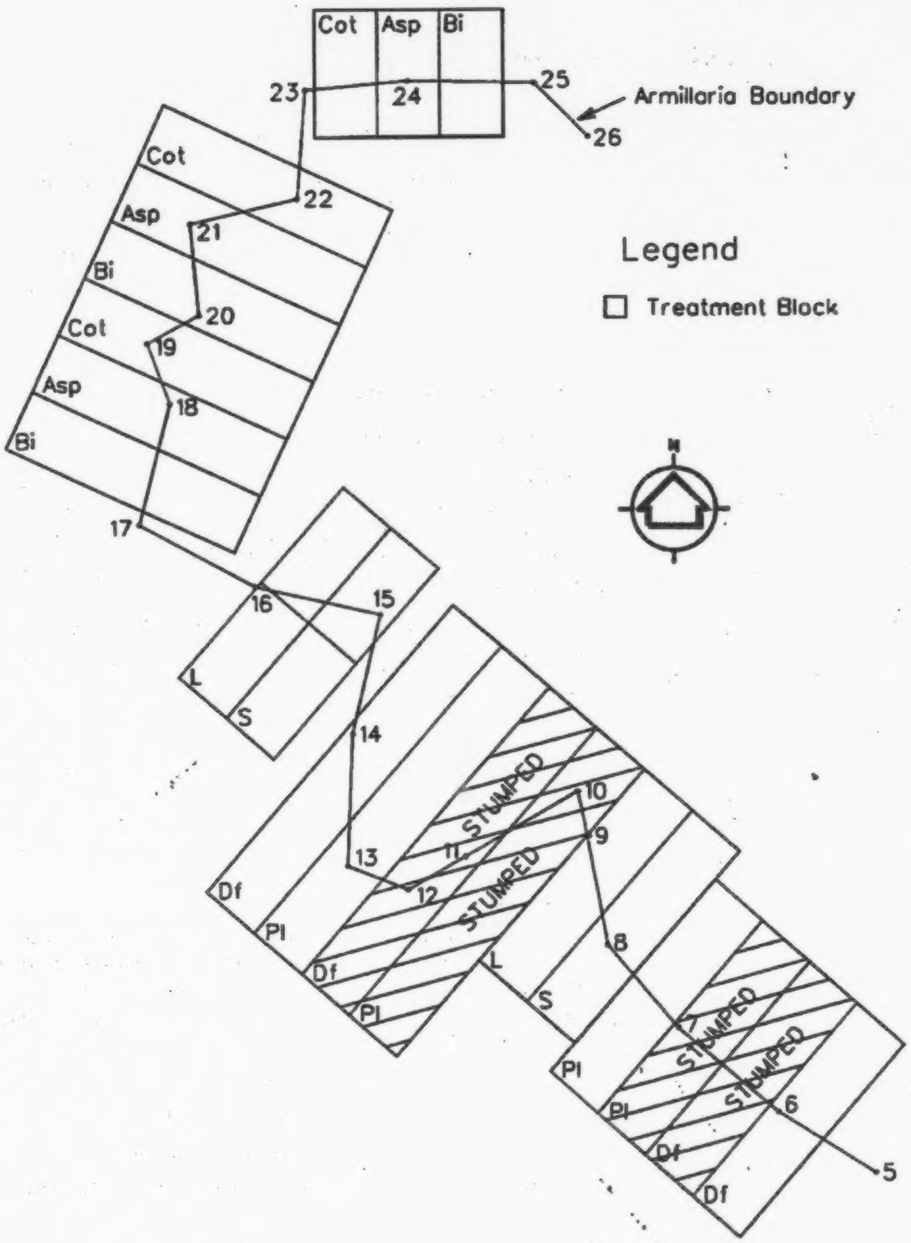
Table 39-A. Site description.

	Site
	Gavin Lake, BC
Region	Cariboo
District	Williams Lake
Opening No.	93A 042-366
Plot Lat/Long	52°27'N/ 121°49'W
Area (ha)	25
Biogeoclimatic Subzone	SBSmh
Site Series	03/04
Slope (%)	Gentle
Aspect	S
Species Composition/ Age(y)/Site Class	OS: F(PlSBiCt)/110/x PL: varied/ 2/x
Total Stems/ha (no.)	OS: 418 PL: 2500
Terrain/ Soil Class./ Soil Texture	x/x/SL
Diseases/Insects	DRA
Stand History	Natural Douglas-fir stand established after 1880's fire; harvested and stumps removed in 1992; planted 1993
Study Establishment	1989
Treatment(s)	1. Stump Removal and Species Trial – clearcutting/stump removal/planting with Douglas-fir and lodgepole pine – clearcutting/planting with Douglas-fir and lodgepole pine 2. Alternate Species Trial – clearcutting/planting with Douglas-fir, lodgepole pine, Interior spruce, larch, birch, aspen, and cottonwood

See Appendix C for abbreviations.

GAVIN LAKE

SCALE: 1:2500


Cot
Asp
Bi
23
24
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Armillaria Boundary
26
Cot
22
Asp
21
Bi
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Cot
19
Asp
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STUMPED
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Legend
☐ Treatment Block
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SUMMARY 40

Project
CFS 8401 (FC-IRM-024)

Monitoring of Long-Term Soil Disturbance in Plantations

Author(s)

E. F. Wass and J. Senyk

Objectives

1. Characterize soil disturbance resulting from stump extraction.

2. Determine whether various categories and depths of disturbance had any effects on the growth of planted trees.

3. Help define the sensitivity of sites and soils to disturbance.

4. Suggest improvements in stumping operations that would reduce soil degradation.

Overview

Layout and Treatments

See Table 40-a for site descriptions.

Phoenix Mountain

Three 20x20-m plots were established in each of four treatments. A total of 200 seedlings (1 + 0 styro-plug) each of Douglas-fir and western larch were planted in six disturbance categories, for a total of 2800 trees for the whole site, as follows.

Treatment	Disturbance Category
Harvested only (not stumped)	1. Undisturbed (400 trees)
Stumped, piled, & raked (raked)	2. Rake (400 trees)
	3. Track (400 trees)
Stumped & piled, deep ruts (non-raked, deep)	4. Scalp (400 trees)
	5. Track (400 trees)
Stumped & piled, shallow ruts (non-raked, shallow)	6. Scalp (400 trees)
	7. Track (400 trees)

Marl Creek

Seven plots of varying size (20x20 to 30x30 m) were established and a total of 600 Douglas-fir seedlings (2 + 0 bareroot stock) and 600 lodgepole pine seedlings (1 + 0 styroblock 213) were planted. Fifty trees of each species were planted in each disturbance category (undisturbed soil, deposit or track) found within each plot as follows:

Treatment	Disturbance Category
3 undisturbed plots	Undisturbed spots only (300 trees)
3 plots with stump uprooting	Deposits & tracks only (600 trees)
1 combined plot	Undisturbed spots, & deposits & tracks (300 trees)

Gates Creek

Three 20x20m plots were established in each of three treatments. A total of

200 seedlings (1 + 0 styro-plug) each of Douglas-fir and lodgepole pine were planted in six disturbance categories and undisturbed ground, for a total of 2400 trees for the whole site, as follows:

Treatment	Disturbance Category
Windrowed only (not stumped)	1. Undisturbed (400 trees)
	2. Tracked (400 trees)
Stumped, windrowed, & raked (raked)	3. Rake (400 trees)
	4. Track (400 trees)
Stumped, windrowed (non-raked)	5. Scalp (400 trees)
	6. Track (400 trees)

At Phoenix Mountain and Gates Creek, the two species were planted in alternate rows in the spring of 1982 at 1x1-m spacing. In spring 1987, trees were thinned in all plots to a minimum spacing of 2 m around each tree, leaving 40-50 trees/disturbance category. At Marl Creek, seedlings were similarly planted in spring of 1985.

Measurements

Soil Disturbance

Ground surveys were conducted to determine the type, depth, extent, and cause of soil disturbance on stumped and non-stumped portions of cutovers following stumping operations. A point intercept method (Smith and Wass 1976) with points spaced at 3-m intervals along a system of transects located and oriented according to Bloomberg et al. (1980) was used. Data collected at each point included the disturbance depth (shallow <5 cm; deep 5-25 cm; very deep >25 cm), disturbance class (gouge, track, deposit, mixture), probable cause of mineral soil disturbance (track, rake, scalp), and presence of windrowed material and vegetative cover. At Marl Creek, a total of 612 points were surveyed and described (also see Summary 26).

Physical and Chemical Characteristics of the Soil

Soils associated with major soil disturbance categories were tested for penetrability, bulk density, pH, and total nitrogen and organic carbon. These measures were compared with those of undisturbed soils.

Seedling Performance

Heights, ground-level diameters, and survival of all seedlings in plots were measured immediately after planting and annually for the next five years. Additional measurements were taken on plantation plots as follows:

- Plant moisture stress - 6 trees/species/disturbance category/plot were randomly selected for pre-dawn and mid-day measurement with a pressure chamber (Waring and Cleary 1967) in the fifth growing season.
- Foliage nutrients - current year foliage samples from six trees/species/disturbance category/plot were randomly selected for nutrient analysis in the fifth growing season.
- Needle weights - weights were taken from the same trees used for foliage nutrient analysis.
- Soil moisture - measurements taken concurrently with plant moisture stress (adjacent to the same trees) at depths of 0-10 cm and 10-20 cm.

- Above-ground biomass - 18 trees/species/plot and 12 trees/species/plot for disturbed categories and undisturbed soil, respectively, were randomly selected and cut for above-ground biomass measurement.
- Root biomass - 3 trees/species/disturbance category/plot were cut for root biomass measurement and examination of root morphology.
- Vegetative cover and species composition - assessments were made according to procedures outlined in Walmsley et al. (1980).

Analysis

Statistical comparisons for soil physical and chemical characteristics and seedling performance variables in different treatments were made using ANOVA followed by Student-Newman-Keuls multiple range tests. Chi-square tests were used to compare soil disturbance levels derived from point transect surveys. Pearson correlation coefficients were used to determine significant correlations among plant moisture stress, seedling growth, and soil moisture parameters.

History/Time Table

1980	Phoenix Mountain and Gates Creek harvested and stumped.
	Survey of soil disturbance/measurement of soil characteristics.
1982	Phoenix Mountain and Gates Creek planted.
1982	Marl Creek harvested and stumped.
	Survey of soil disturbance/measurement of soil characteristics.
1985	Marl Creek planted.
	Tree growth measured annually for the first five years.
1989	Year 8 growth re-measurement at Phoenix Mountain and Gates Creek.
1992	Year 8 growth re-measurement at Marl Creek.

Tree growth will be re-measured at Year 10, 15, and 20 and soil characteristics will be re-measured in the Year 15 at all sites.

Status

Ongoing.

Brief Summary of Results

Phoenix Mountain

In the raked treatment, 100% of the surface was disturbed with mineral soil exposed. Major categories of disturbance were tracks, rakes, and non-raked scalps. The non-raked area also had 100% mineral soil exposed with major categories being scalps and tracks. Compared to the raked treatment, significantly more of the disturbance in the piled, non-raked treatment was classed as very deep. There was little difference between bulk densities of undisturbed soil and rake and track disturbances in the raked treatment. In the non-raked treatment, deep tracks were significantly denser than scalps or undisturbed soil. After eight years, Douglas-fir growing on the undisturbed soil were generally smaller than those growing on disturbed spots (except for tracks and rakes in the raked treatment). The average height and volume of western larch growing on undisturbed soil was less than that of fir growing in all other disturbance categories (except rakes and tracks in the raked treatment). The best growth occurred on scalps in the non-raked (deep) treatment.

Marl Creek

The area was 72% disturbed by the stumping operation, of which 42% resulted from stump removal and 30% from tractor tracks. The top 20 cm of soil in tracks was, on average, about 23% denser and 68% less penetrable than the equivalent layer of undisturbed soil. In contrast, deposits were about equal in density to undisturbed soil and, at depths of 15 and 20 cm, were about half as resistant to penetration. After eight growing seasons, Douglas-fir planted on tracks were significantly smaller in height and diameter (12-14%) than trees planted on deposits or undisturbed soil. Lodgepole pine planted on tracks were on average significantly (12%) smaller than those planted on deposits or undisturbed soil.

Gates Creek

In the non-stumped but windrowed treatment, 68% of the area was classified as disturbed. Disturbance resulted mainly from bulldozer tracks and log yarding. Mineral soil exposure was 100% in the raked and non-raked treatments. Rakes, tracks, windrows, and scalps were major disturbance categories in the raked treatment; disturbance in the non-raked treatment was due mainly to scalps, tracks, and windrows. The amount of very deep disturbance was significantly less for the windrowed, non-stumped treatment than either of the stumped treatments. There were no significant differences in bulk density among disturbance categories in the raked treatment, but all disturbed soils were significantly denser than the undisturbed soil. In the non-raked treatment, tracks were significantly denser than both the undisturbed soil or scalps. After eight years, there was a trend for average height, diameter, and volume of Douglas-fir growing in undisturbed soil to be greater than for this species growing on any of the disturbed plots.

Differences were significant for height and volume with tracks in both raked and non-raked treatments, and for volume in the raked treatment. Average volumes on tracks in raked and non-raked were less than 50% of trees growing on undisturbed soil. The average size of lodgepole pine growing on undisturbed soil tended to be greater than in disturbed categories, but no differences were significant. The authors attributed poor growth of trees in tracks on stumped treatments to their proximity to temporarily ponded water.

The authors' recommendations included: limiting stumping to less sensitive sites, eliminating the windrowing phase and leaving stumps in place, extracting stumps with an excavator rather than a bulldozer to reduce deep gouging, and using sufficiently wide, rear-mounted equipment for root raking to decompact the prime mover tracks and help maintain soil productivity.

Working Plans/Reports/

Smith, R.B. and Wass, E.F. 1984. Preliminary assessment of impacts of two stumping operations on site productivity, Interior British Columbia. pp. 247-

Publications

251 in: New Forests for a Changing World. Proc. 1983 Soc. Amer. For. Conv., Oct 16-20, Portland, Oregon.

Smith, R.B. and Wass, E.F. 1991. Impacts of two stumping operations on site productivity in Interior British Columbia. Can. For. Serv. Pac. For. Res. Cent. Inf. Rep. BC-X-327. 43 pp.

Smith, R.B. and Wass, E.F. 1994. Impacts of a stump uprooting operation on properties of a calcareous loamy soil and on planted seedling performance. Can. For. Serv., Pac. For. Res. Cent., Inf. Rep. BC-X-344. 19 pp.

Wass, E.F. and Smith, R.B. 1994. Impacts of soil disturbance on root systems of Douglas-fir and lodgepole pine seedlings. Can. For. Serv., Pac. For. Cent., Inf. Rep. BC-X-348. 22 pp.

Maps

See above reports.

Table 40-a. Site descriptions.

	Site		
	Phoenix Mountain	Marl Creek	Gates Creek
Region	Nelson	Nelson	Kamloops
District	Boundary	Golden	Vernon
Opening No.			
Plot Lat/Long	49°05'N 118°37'W	51°33'N 117°11'W	50°22'N 119°35'W
Area (ha)	10	32	24
Biogeoclimatic Subzone/Site Series	ICHmk1/x	ICHmw1/x	IDFmw1/x
Slope (%)	12	19 (range 0 - 48)	
Aspect	W	SW	
Species Comp./Age/Site Class	FdPlLw uneven aged	FdPlSx(At)	FdPl 80-100 y
Stems/ha (no.)		573 + 95 dead	
Terrain/Soil Class./Soil Texture	x/GT; GSL/x	x/CV and GT; GSL/x	x/GT; GSL/x
Diseases/Insects	DRA	DRA	DRL
Stand History			L
Study Establishment	1981	191983	1981
Treatment(s)	Conventionally harvested (fall 1980), stumped (fall 1980): 1. stumped, piled and raked with a D8H-cat; 2. stumped and piled with a D8H-cat; 3. not stumped.	Conventionally harvested (fall 1982), stumped (spring 1983): 1. 1980 D7G 200FWHP (149kw); 2. 1978 D8K, 300 FWHP (224kw).	Conventionally harvested (winter 1980), stumped (fall 1980): 1. stumps extracted and windrowed with a D8H-cat equipped with a brush blade; 2. raked with a brush blade to bring large roots to the surface; 3. windrowed but stumps not removed.

See Appendix C for abbreviations.

SUMMARY 41

Project **Appraisal and Analysis of Available Data Regarding Distribution and Incidence of Armillaria Root Disease in the Nelson Forest Region**

Author(s) K. White and A. Pollard

Study Objectives

1. Summarize available data on the distribution and incidence of Armillaria root disease in the Nelson Forest Region and to statistically analyze recent data where appropriate.

2. Review and compare current study results to other studies, primarily from the Nelson Forest Region.

Overview

Layout and Treatments

N/A.

Measurements

Database Compilation

Three data sets were compiled and appraised: Integrated Silviculture Information System (ISIS), Comprehensive Pest Inventory (CPI), and regional pixel surveys. Following is a brief summary of each data set.

ISIS (data from 1990-1994). Primarily a silvicultural database that allows entry and updating of Silviculture Prescriptions and the recording of treatments to Activity Treatment Units. Most of the records in ISIS are of immature stands. While ISIS contains forest health observations, they are a secondary objective of the database. (The forest health portion of the new silviculture survey forms (FS 759) will permit recording of pest incidence down to the host tree level.)

The limitations of ISIS are:

- inconsistent recording of pest incidence (in percent) and incidence area;
- most of recorded data is derived (summary of survey information); and
- incidence area is normally recorded by multiplying the pest incidence by the total area of the opening, which does not take into account the variation of DRA occurrence within an opening.

CPI (data from 1987-1992). CPI records pest incidence within mature forest cover polygons. Specific criteria used in polygon selection were listed in the Ministry of Forests report *Augmenting the AAC Through Pest Treatment* (Mackenzie 1991). These criteria were based on previous experience with DRA in the Nelson Forest Region. Very few non-suspect polygons were surveyed, making the data set biased.

The limitations of CPI are:

- not designed for projecting losses due to DRA over large areas;
- incomplete sampling of Districts and biogeoclimatic zones;
- non-random polygon selection; and
- incomplete data sets (i.e. no information on pest incidence, BEC information, tree species etc.), i.e. less than 10% of the CPI data set contained complete records.

Pixel Surveys (data mostly from 1992 to 1994). Pixel surveys report DRA results from surveys undertaken by Districts in openings believed to contain DRA. The purpose of these surveys are to provide accurate levels of DRA. The available data includes stands of various ages.

The limitations of pixel surveys are:

- survey information limited to three forest districts, i.e. Arrow Lake, Cranbrook, and Invermere;
- non-random polygon selection; and
- information other than that directly related to DRA is inconsistently recorded.

Limitations Common to All Surveys. Some limitations were common to all surveys:

- None can accurately determine the incidence of DRA. The reason behind this inability lies partly with the survey methods used. The ISIS data contains surveys of three types: line, plot, and pixel. The CPI and Pixel survey data are based on the plot and pixel surveys, respectively. Each survey type provides different information. For example, in a pixel survey, actual tree numbers and species infected are not recorded. Information provided does not include percent pest incidence; only the presence or absence of the disease is noted.
- All data sets lack proportional representation of the different biogeoclimatic subzones. Only four biogeoclimatic zones are consistently surveyed in the Nelson Forest Region: ESSF, ICH, IDF, and MS. BEC zone and subzone are not always recorded.
- No information is provided in any of the data sets as to which tree species within the given sample area shows symptoms of the disease.

Comparison with Other Documents

An annotated bibliography of information accumulated by forest health staff was compiled to identify reports with similar objectives. See the report.

Analyses

Database Compilation

Only the ISIS and Pixel Survey data were used in the analysis, due to the incomplete nature of the CPI data set.

Data bases were compiled in Microsoft Access® and analysed in Microsoft Excel®.

Statistical analyses of the databases included:

- mean pest incidence percentage, standard deviation, and standard error;

- median pest incidence percentage and quartiles;
- number of surveys with and without DRA; and
- survey areas with and without DRA.

Medians were used to give a better representation of the central tendency of the data, due to the wide variation in pest incidence percentage within some groups (biogeoclimatic zones, ITGs). The percentage of surveys with DRA was calculated by dividing the number of survey units (openings, polygons, sub-polygons) infected with DRA by the total number of surveys. The percentage of survey area infected was calculated by dividing the survey area infected with DRA by the total area surveyed.

Mean and median pest incidence percentages were compared for four main parameters:

1. biogeoclimatic zone and subzone;
2. inventory (or growth) type groups (ITGs);
3. tree density (total stems per hectare); and
4. average tree age.

When possible, both ISIS and pixel survey data were used to produce two sets of statistics for comparison.

Data were summarized in tables and graphs. The two types of graphs are:

1. plots of mean percent incidence of DRA against the percent of survey area infected by DRA; and
2. median percent incidence of DRA with the percent of surveys infected by DRA.

Comparison with Other Documents

Few direct comparisons to the results of this report were found. Very general comparisons were made to add information and to note trends. (Refer to the main report for further information.)

History/Time Table

1995-96	Initiated and completed.

Status

Complete.

Brief Summary of Results

General Interpretations

There were many problems with the existing data sets. Inconsistencies included: missing real data, biases, and incomplete records. Keeping the inherent problems of the two data sets in mind, summary data showed:

- An average incidence of DRA of 24.5% was found in 20.5% of the survey area (or 19.2% of the surveys) in ISIS.
- An average incidence of DRA of 13.9% was found in 49% of the survey area (or 46.5% of the surveys) in the pixel survey data.
- DRA was found in all of the biogeoclimatic zones and subzones sur-

veyed.

There were few similarities between the ISIS and pixel survey graphs for the same parameter. This is likely a reflection of the different characteristics of each data set.

Due to the biased nature of the data sets, the authors state that the results could not be projected onto a greater population, which was one objective of the project. The extent to which the results can be interpreted in terms of distribution and incidence has not yet been determined. The data will be interpreted by a statistician at a future date to further clarify the quality of the data sets and determine the sort of conclusions that can be drawn.

Recommendations [32]

1. A new standard survey should be designed to determine DRA, and other root disease, incidence in natural and managed stands. This new survey needs to provide an accurate picture of incidence within a survey area and also of the tree species affected. Original field data should not be summarized into a single statistic (percentage of pixels infected).

2. Basic information required includes: survey location, survey area, survey intensity, forest cover information (ITGs or species composition), site index, site stocking, tree age and height, tree density (total stems/ha and well-spaced stems/ha), DRA incidence, tree species affected by DRA (host species), BEC information down to the level of subzone or variant, and if possible, to the site series or site association, and some measure of disease severity.

3. Survey areas need to be randomly selected, in order for any of the analysis results to be projected over a larger area. Surveys should be carried out in all biogeoclimatic zones, in proportion to the total area of the biogeoclimatic zone within the area of interest.

4. A standard method of data storage needs to be developed in co-ordination with the new survey method.

5. There must be an examination of the requirements needed for the data that will be used for growth and yield projects.

Working Plans/Reports/Publications

White, K. and A. Pollard. 1995. Appraisal and analysis of available data regarding distribution and incidence of Armillaria root disease in the Nelson Forest Region. Silviculture Practices Branch, BCMOF. Victoria. Forest Service Internal Report FH-SB-03. (Not for Publication)

Maps

None.

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[32] Some of the recommendations have been addressed in the new Forest Level Multi-Pest Survey (FLMPS) currently under evaluation. A standard survey method would permit the sharing of DRA data within and between Regions. This would provide an overview of the distribution and natural severity of this root disease.

SUMMARY 42

Project

Behaviour and Impacts of *Armillaria ostoyae* on Mature Stands and Plantations in the Shuswap Region of British Columbia

Author(s)

A. Woods and B. J. van der Kamp

Study Objectives

The main objective was to better understand the development of *Armillaria ostoyae* in mature stands and plantations established on sites with a previous history of this disease.

Specific objectives were:

1. Document the relationship between pre-harvest and post-harvest expression of *Armillaria ostoyae.*

2. Rank conifer species according to their susceptibility to *Armillaria ostoyae* in mature stands and plantations.

3. Evaluate the relationship between *Armillaria ostoyae* plot severity and factors including biogeoclimatic site unit,[33] site index, disturbance history and elevation in mature stands.

4. Document the expression of *Armillaria ostoyae* over a range of plantation ages, and under different silvicultural treatments (i.e. brushing).

Overview

Layout and Treatments

See Table 42-a for site descriptions.

Mature Stands

The main study area, Hunter's Range, was chosen because it included *Armillaria ostoyae*, two biogeoclimatic zones (ICH and IDF), and was relatively easy to access. Evidence of past logging disturbance was scattered throughout the area.

At Hunter's Range two hundred and two 8-m radius (0.02-ha) cruise plots were systematically located at 200-m intervals on pre-established cruise strips. The strips run east-west against the contour of the hillside to capture the greatest elevation variation. The site is located in a biogeoclimatic transition area between three subzones: ICH mw2, ICH mk1, and IDFmw1. The three subzones were not equally represented in the 202 plots.

The following summer a second study area was selected to verify the trends in species susceptibility observed in the Hunter's Range data. Thirty-two plots were located and measured at Larch Hills, in a similar manner to those at Hunter's Range. Both sites were similar in aspect, biogeoclimatic classification, disturbance history, and timber types.

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[33] Site series.

Plantations

Four plantations were selected within the ICH biogeoclimatic subzone (Larch Hills). Selection criteria included: suitable site preparation, i.e. broadcast burned rather than mechanical; clearly defined date of establishment; reasonable site proximity; ease of access; and presence of *Armillaria ostoyae*. The four plantations represented a range in ages: one at 10 years, one at 15 years, and two at 25 years old. One 25-year-old stand had been brushed.

In each of the four plantations, fifty 8-m radius plots were systematically established at 100-m intervals on strips spaced 100 m apart.

Measurements

Mature Stands

The following information was collected at each plot:

- Species, dbh, and estimated height for each tree.
- Tree and plot disease codes (Table 42-b).
- Disturbance history rating (Table 42-b).
- Biogeoclimatic subzone and site unit.
- Site index (based on Thrower and Goudie's (1992) site index for Interior Douglas-fir).
- Elevation.
- Total volume for each species using local volume tables for each.
- Species and diameter at root collar for all stumps.

Each plot was also assigned a severity rating, as outlined in Table 42-c.

Plantations

The following information was collected at each plot:

- Species and number of stumps per plot.
- Disease status for each stump classified as: DRA not present; DRA present prior to harvest; DRA present following harvest. The latter two classes were differentiated based on mycelial fan impression morphology.
- Tree species, height, and diameter at root collar for all regeneration >30-cm high.
- Armillaria incidence in regeneration >30-cm high: basal resinosus or chlorotic foliage were used to identify which trees to examine and confirm the presence/absence of Armillaria, i.e. presence of mycelial fans.

Each plot was also assigned a severity rating, as outlined in Table 42-c.

Analyses

Mature Stands

Multiple correlation analysis was used to investigate the relationship between plot disease severity rating and the following measured site and stand variables: volume per tree species, basal area per tree species, biogeoclimatic site unit, site index, site disturbance rating, and elevation. The plot severity rating was the dependent variable.

Five of the conifer species at both the Hunter's Range and Larch Hills sites were compared to determine the Incidence of Armillaria infection. The proportion of Douglas-fir infected with Armillaria was chosen as a standard measure of infection for the two areas. The proportion of the other species infected was compared to the Douglas-fir standard using a Chi-square test to rank the susceptibility of conifer species to infection.

Plantations

Correlation analysis was used to examine the relationship between: pre-harvest Armillaria incidence based on stump evidence, and post-harvest Armillaria incidence in the regenerated stands. The proportions of trees infected in the two 25-year-old plantations were compared to assess the impacts of brushing *Armillaria ostoyae*-infected juvenile stands. Similar to the mature stand study, the proportion of infected Douglas-fir was chosen as a standard measure of Armillaria incidence. The proportion of trees infected for seven conifer species were compared to the Douglas-fir standard to determine a ranking of species susceptibility in the conifer regeneration using a Chi-square test. Refer to the original paper for discussion of results.

History/Time Table

Summer 1992	Trial of survey techniques. Commence main survey.
September -	
December 1992	Analysis of data. Consultation with interested parties and agencies.
January 1993	Review of first year results and modification of objectives.
May 1993 -	
March 1994	Survey completed, data compilation, and report writing.

Status

Completed.

Brief Summary of Results

Mature Stands

In the Hunter's Range stand, 170 of 202 plots examined (84%) exhibited signs of either *Armillaria* spp., *Phellinus weirii*, or both. Thirty of the 32 plots in the Larch Hills stand exhibited signs of either Armillaria, Phellinus, or both. Armillaria plot severity varied considerably within stands. At both study locations, the IDF stands contained less Armillaria and more Phellinus, compared to the stands in the ICH.

Of the site factors examined, past logging was the only one that correlated significantly with Armillaria plot severity rating (r=0.329). Correlation coefficients for the other factors were: site index at 0.016, and elevation at 0.040.

The correlation between Armillaria plot severity rating and total plot tree volume was significant for the 120-year-old stand in the ICH zone. The plots with highest Armillaria severity had significantly lower total conifer volumes than the plots with lower Armillaria incidence. There was no significant difference in conifer volumes between those plots with moderate levels of infection and those with very low infection severities. The relationship between Armillaria plot severity rating and total conifer volume in the IDF zone was not significant. There was, however, a clear trend of lower total conifer volume with increasing Armillaria plot severity.

The ranking of conifer species to Armillaria susceptibility was based on the percentage of infected trees. The rankings differed between the Larch Hills and Hunter's Range sites as well as between the ICH and IDF zones within each of the study areas. Table 42-d lists tree species in order of frequency of infection for each zone within each study area.

The species susceptibility ranking was considerably different from that reported in the literature, particularly with regards to Douglas-fir and western larch susceptibility (Morrison et al. 1991). With the exception of the Hunter's Range stand in the ICH, western larch was more frequently infected with Armillaria than Douglas-fir, contrary to the species susceptibility rankings of Morrison et al. (1991). Similarly, lodgepole pine and western red cedar were more frequently infected than Douglas-fir across all sites.

Plantations

Pre- and post-logging infection of stumps were distinguishable on the basis of differences in mycelial fan impression morphology in the inner bark. Preharvest mycelial fans were contorted and deeply etched while post-harvest fans were typically expansive and lightly etched. Some stumps had deteriorated to such an extent that it was not possible to identify whether they had been infected or not. Pre- and post-harvest stump infection measures were significantly, but not strongly, correlated with Armillaria incidence in the regeneration with the highest r-value of only 0.403 (Tables 42-e and 42-f).

Due to the small sample size of only four plantations, it was not possible to explore the relationship between plantation age and *Armillaria ostoyae* incidence and impact.

Of the four plantations, only two—the 10-year-old and the brushed 25-year-old—were similar enough with respect to site conditions, species composition, and pre-treatment Armillaria incidence to permit even an observational comparison of Armillaria incidence. On the 25-year-old plantation, Armillaria plot severity rating was less than that of the 10-year-old plantation. Further discussion was limited due to the absence of replication and variation between the plantations in influential factors such as stock type.

Disease incidence was significantly higher in the 25-year-old plantation that had been brushed and juvenile spaced than in the 25-year-old plantation that had not been brushed. Only 1.8% of the Douglas-fir stems >12.5-cm diameter at root collar were infected in the unbrushed stand, while 8.5% of the stems in the same categories in the brushed stand were infected.

Working Plans/Reports/ Publications

Morrison, D.J., H. Merler, and D. Norris. 1991. Detection, recognition and management of Armillaria and Phellinus root diseases in the southern Interior of British Columbia. FRDA II. Research Branch, BCMOF. 25 pp.

Woods, A.J. 1994. The behaviour and impacts of *Armillaria ostoyae* in mature stands and plantations in the Shuswap region of British Columbia. Department of Forest Sciences, UBC. Vancouver. M.Sc. thesis. 121pp.

Draft paper on species susceptibility ranking for submission to Can. J. For

Research (in progress).

Maps None. Sites temporary.

Table 42-a. Site descriptions.

	Site					
	Hunter's Range	Larch Hills	Larch Hills	Larch Hills	Larch Hills	Larch Hills
Region	Kamloops	Kamloops	Kamloops	Kamloops	Kamloops	Kamloops
District	Salmon Arm	Salmon Arm	Salmon Arm	Salmon Arm	Salmon Arm	Salmon Arm
Opening No.						
Plot Lat/Long						
Study Area (ha)	≅ 4000	≅ 2000	110	80	15	60
Biogeoclimatic Subzone/ Site Series	ICHmw2 01-05, IDFmw1 01-04 ICHmk1 01-03	ICHmw2 01-03 IDFmw1 01	ICHmw2	ICHmw2	ICHmw2	ICHmw2
Slope (%)	0 - 75%	0 - 75%	< 30%	< 30%	< 30%	< 30%
Aspect	W	NW	E	E	E	E
Species Compn./ Age(y)/ Site Class	OS: Fd(Pl,Cw,Lw,Hw) age class 6-7/M	OS: Fd(Lw,Pl,Cw) age class 6-7/M	OS: x PL: Fd(Cw,Hw,Pl,Ep) 25 y/M	OS: x PL: Fd(Cw,Hw,Sw) 25 y/M	OS: x PL: Pl(Fd,Ep,Cw) 15 y/M	OS: x PL: Fd(Pl,Ep,Cw,Sw) 10 y/M
Stems/ha (no.)	OS: ICH 900 OS: IDF 700	OS: ICH 900 OS: IDF 700	OS: x PL: 2203	OS: x PL: 2098	OS: x PL: 1610	1985
Terrain/Soil Class./Soil Texture	x/x/x	x/x/x	x/x/x	x/x/x	x/x/x	x/x/x
Diseases/Insects	DRA, DRL	DRA, DRL	DRA	DRA	DRA	DRA
Stand History	fire origin ≅ 1870's some selective logging '40-50's	fire origin ≅ 1870's some selective logging '40-50's	logged 1968, burned 1968, planted 1969 Fd 1000 Stems/ha (no.)	logged 1965, burned 1967, planted 1969 Fd 1300 Stems/ha (no.) brushed 1984/1986	logged 1974, burned 1976, planted 1980 Pl 1000 Stems/ha (no.)	logged 1979, burned 1980, planted 1984, Fd/Pl 1200 Stems/ha (no.) brushed 1987
Study Establishment	1992	1993	1993	1993	1993	1993
Treatment	None	None	None	None	None	None

See Appendix C for abbreviations.

Table 42-b. Tree and plot disease codes and disturbance ratings.

Tree Disease Code		Plot Disease Code		Disturbance History Rating	
0	No evidence of disease[a]	0	No evidence of disease in plot	0	No disturbance
2	Healed over basal lesion[b]	1	Evidence of disease on trees <10-cm dbh or dead and downed trees	1	Disturbance outside of plot radius (i.e. stumps or skid trails)
3	Active mycelium and/or recent mortality	2	Presence of disease code 2 trees >10-cm dbh within plot	2	Cut stumps present within plot
		3	Presence of disease code 3 trees >10-cm dbh within plot		

[a] Evidence of disease = presence of active mycelium or mycelial fan etching in the inner bark or rhizomorphs.

[b] Healed over basal lesion = infections that have been callused over with bark and no longer contain active mycelium.

Table 42-c. Armillaria severity rating.

Rating	Class 2	Class 3
0	No evidence of Armillaria in plot.	
0.0-0.1	1	3
0.1-0.2	2	6
0.2-0.3	3	9
0.3-0.4	4	12
0.4-0.5	5	15
0.5-0.6	6	18
0.6-0.7	7	21
0.7-0.8	8	24
0.8-0.9	9	27
0.9-1.0	10	30

Table 42-d. Species ranked by frequency of Armillaria ostoyae infection.

Rank	Site			
	Hunter's Range ICH	Hunter's Range IDF	Larch Hills ICH	Larch Hills IDF
1	Pl	Pl	Cw	Cw
2	Pw	Cw	Pl	Lw
3	Bl	Lw	Lw	Pl
4	Cw	Fd	Ep	Fd
5	Hw	Ep	Fd	Ep
6	Fd			
7	Se			
8	Lw			
9	Ep			

Table 42-e. Stumps infected with Armillaria ostoyae in each plantation.

Disease status	Plantation [a]							
	1969a		1969b		1980		1984	
	(%)	(no.)	(%)	(no.)	(%)	(no.)	(%)	(no.)
Pre-harvest	38.9 (1)		50.5 (2)		46.5 (2)		38.5 (1)	
Post-harvest	19.8 (1)		19.9 (1)		36.6 (2)		32.1 (2)	
Total stumps		368		402		462		730

[a] Percentages followed by the same number in brackets are not significantly different from the others in that row based on Chi-square tests (α=0.05).

Table 42-f. Conifers in each plantation killed by, or dying from, Armillaria ostoyae.

Trees	Plantation							
	1969a		1969b		1980		1984	
	(%)	(no.)	(%)	(no.)	(%)	(no.)	(%)	(no.)
Dead trees	1.7		7.3		10.1		5.1	
Dying trees	0.3		1.4		1.2		0.6	
Total		2203		2098		1610		1985

SUMMARY 43

Project **Armillaria Silviculture Trial**

Author(s) D. Wright, S. Henderson, and D. Doidge

Objectives 1. Determine a silvicultural method that will enable an Armillaria-infested stand achieve free-growing status, within the 100 Mile House Forest District.

Overview

Layout and Treatments

See Table 43-a for site descriptions.

When the three study areas were harvested, it was not known that the areas contained a high concentration of Armillaria. Subsequently, at each study area, preliminary root disease survey(s) of varying intensity were conducted (see below).

To maximise homogeneity of site characteristics, including Armillaria incidence, 16-ha study areas were identified within each study area. The Timothy, Young, and Wilcox Lake Study sites were each divided into sixteen ~1-ha during the spring of 1993. There were four treatments and four replicates per treatment.

Treatment locations at each site were determined randomly and the following treatments were implemented:

1. *Control (no treatment).* Plots left untreated to measure relative infection rates.
2. *Residual tree harvesting and mechanical stumping.* Stumps (left from harvesting and spacing) and residual conifers were pulled out of the ground and then windrowed into piles with an excavator with a bucket attachment; residual trees were pushover logged; and the treatment site was planted.
3. *Residual tree harvesting, mechanical stumping and raking.* Stumps were pulled out of the ground and windrowed into piles using an excavator with a bucket attachment; raking was carried out with a rake attachment to remove smaller roots up to 5 cm in diameter; and the treatment site was planted.
4. *Fill plant.* Selected trees species were planted in alternating rows and spaced off of residual trees.

Each 1-ha treatment unit was subdivided into three equal portions to test three different planting regimes: planting with susceptible species, planting with a combination of susceptible and less susceptible species, and planting with less susceptible species.

The planting regimes for each site are summarized below:

Site	Subplot	Planting design	Species
Timothy	A	Susceptible species	Douglas-fir
	B	Combination	Lodgepole pine/birch
	C	Less susceptible species	Western larch
Young	A	Less susceptible	Yellow pine or western larch
	B	Combination	Birch/lodgepole pine
	C	Susceptible species	Douglas-fir
Wilcox	A	Susceptible species	Douglas-fir
	B	Combination	Spruce/western larch
	C	Susceptible species	Lodgepole pine

All trees were planted by one tree planter to ensure continuity in the quality of planting. In each of the 16 plots, a selected number of planted trees were labelled with a numbered tag. Sites will be monitored on an ongoing basis.

Measurements

Pre-Treatment Root Disease Surveys

Timothy Lake. Two pixel surveys were conducted with each pixel measuring 15x25 m. In summer 1992, 30-m strip lines were installed throughout the opening.

Young Lake. One pixel survey (15x25-m pixels) was conducted in summer of 1993 with 30-m strip lines installed throughout the entire opening.

Wilcox Lake. Two pixel surveys were conducted with each pixel measuring 15x25 m. In fall 1992, 100-m strip lines were installed in the southern two thirds of the opening and a walk through was conducted in the northern third. In spring 1993, 30-m strip lines were installed with 100% coverage of the entire opening.

Tree Tagging

The tagging of trees took place after all three sites had been planted. Each site was assigned a series of multi purpose plastic numbered tags that were attached to metal silviculture stakes. Each site is numbered as follows:

Timothy Lake	001- 2041
Wilcox Lake	2388 - 4480
Young Lake	4507 - 7359

Survival Surveys of All Tagged Trees

Each plot will be revisited, and the diameter and height of the tagged trees will be measured and recorded for analysis. The percent of all planted and naturals trees in each plot showing one or more signs and symptoms of Armillaria root rot, e.g. red foliage, mycelial fans, basal resinosis, basal lesions, will be noted.

Surveys of Free Growing

A walk-through and visual assessment of growth will be conducted in each plot. Survival of the tagged trees in each plot will be determined and whenever possible, mortality agents, e.g. Armillaria and competition, will be identified.

Analysis

Summary statistics, comparison tables and graphs will be used to determine the efficacy of the established treatments in aiding an Armillaria-infested stand to reach free-growing status.

History/Time Table

Timothy Lake	1983	Harvested.
	1984	Regeneration survey.
	1993	Silviculture survey.
		Pre-treatment root disease surveys.
	1994	Stumped and raked.
	1995	Planted.
Young Lake	1960	Harvested.
	1984	Harvested.
	1986	Juvenile spaced.
	1993	Silviculture survey.
		Pre-treatment root disease surveys.
	1994	Stumped and raked.
	1995	Planted.
Wilcox Lake	1978	Harvested.
	1981	Regeneration survey.
	1983	Planted.
	1988	Regeneration survey.
	1992	Forest health survey.
	1993	Silviculture survey.
		Pre-treatment root disease surveys.
		Stumped and raked.
	1995	Planted.
All Sites	1996	Survival study of all tagged trees.
	1997	Survival study of all tagged trees.
	2000	Survival study of all tagged trees.
	2005	Survival study of all tagged trees.
	2010	Free growing survey.
		Root disease survey.

Status

Ongoing.

Brief Summary of Results

Pre-Treatment Root Disease Surveys

Timothy Lake. 92% of the area (69.4% of pixels) was infected with Armillaria in moderate to heavy concentrations.

Young Lake. 93% of the area (78.4% of pixels) was infected with Armillaria in moderate to heavy concentrations.

Wilcox Lake. 86.7% of the area (54.6% of pixels) was infected with Armillaria in moderate to heavy concentrations.

Working Plans/Reports/Publications

A report on free-growing status will be written in 2010.

Maps

See following.

Table 43-a. Site descriptions. Prior to Treatment.

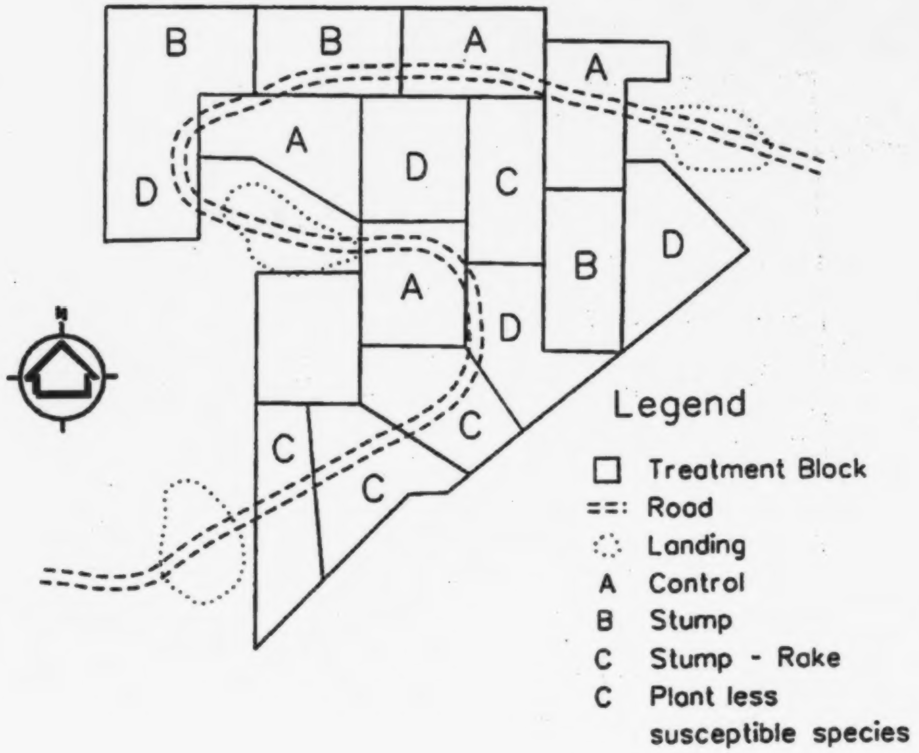
	Site		
	Timothy Lake	Young Lake	Wilcox Lake
Region	Cariboo	Cariboo	Cariboo
District	100-Mile House	100 Mile House	100 Mile House
Opening No.	92F 084-16	92P 025-10	92P 085-12
Plot Lat/Long	51°51.00'N 121°18.00'W	51°16.00'N 121°01.00'W	51°50.00'N 121°08.00'W
Area (ha)	14.1	16.1	16.1
Biogeoclimatic Subzone/Site Series	IDFdk3/01	IDFdk3/SBPSmk	SBSdw 1/01
Slope (%)	10	4	10
Aspect	variable	variable	variable
Species Comp./Age/Site Class	EpFdAtSx/110/M2	Fd(Pl)/210/P1	AtEpFdSx/110/G2
Stems/ha (no.)	8883	2325	9212
Terrain/Soil Class./Soil Texture	even/Mor (1.5 cm)/SIL	even/Mor (2-4 cm)/SICL	even-rolling/Moder/SIL
Diseases/Insects	DRA	DRA	DRA
Stand History	Selectively Harvested: 1983 Stumped/Raked: 1994 Planted: 1995	Selectively Harvested: 1960 Selectively Harvested: 1984 Spaced: 1986 Stumped/Raked: 1994 Planted: 1995	Harvested: 1978 Planted: 1983 Stumped/Raked: 1993 Planted: 1995
Study Establishment Treatment(s)	1. Control (no treatment) 2. Stumped and planted with a mixture of species 3. Stumped, raked and planted	1. Control (no treatment) 2. Stumped and planted with a mixture of species 3. Stumped, raked and planted	1. Control (no treatment) 2. Stumped and planted with a mixture of species 3. Stumped, raked and planted

	with a mixture of species 4. Fill planted with a mixture of species	with a mixture of species 4. Fill planted with a mixture of species	with a mixture of species 4. Fill planted with a mixture of species

See Appendix C for abbreviations.

TIMOTHY

SCALE: 1:5000



B
B
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A
A
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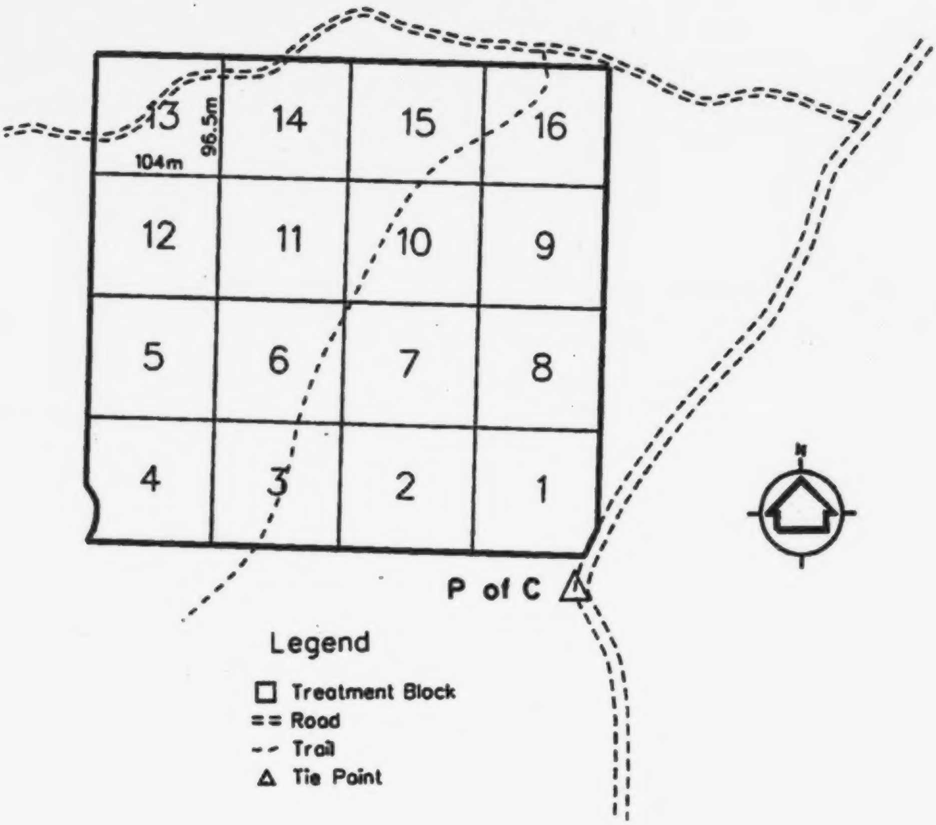
D
C
D
B
A
D
C
C
C
N
Legend
☐ Treatment Block
=== Road
Landing
A Control
B Stump
C Stump - Rake
C Plant less susceptible species

YOUNG LAKE

SCALE: 1:5000


13
104m
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☐ Treatment Block
== Road
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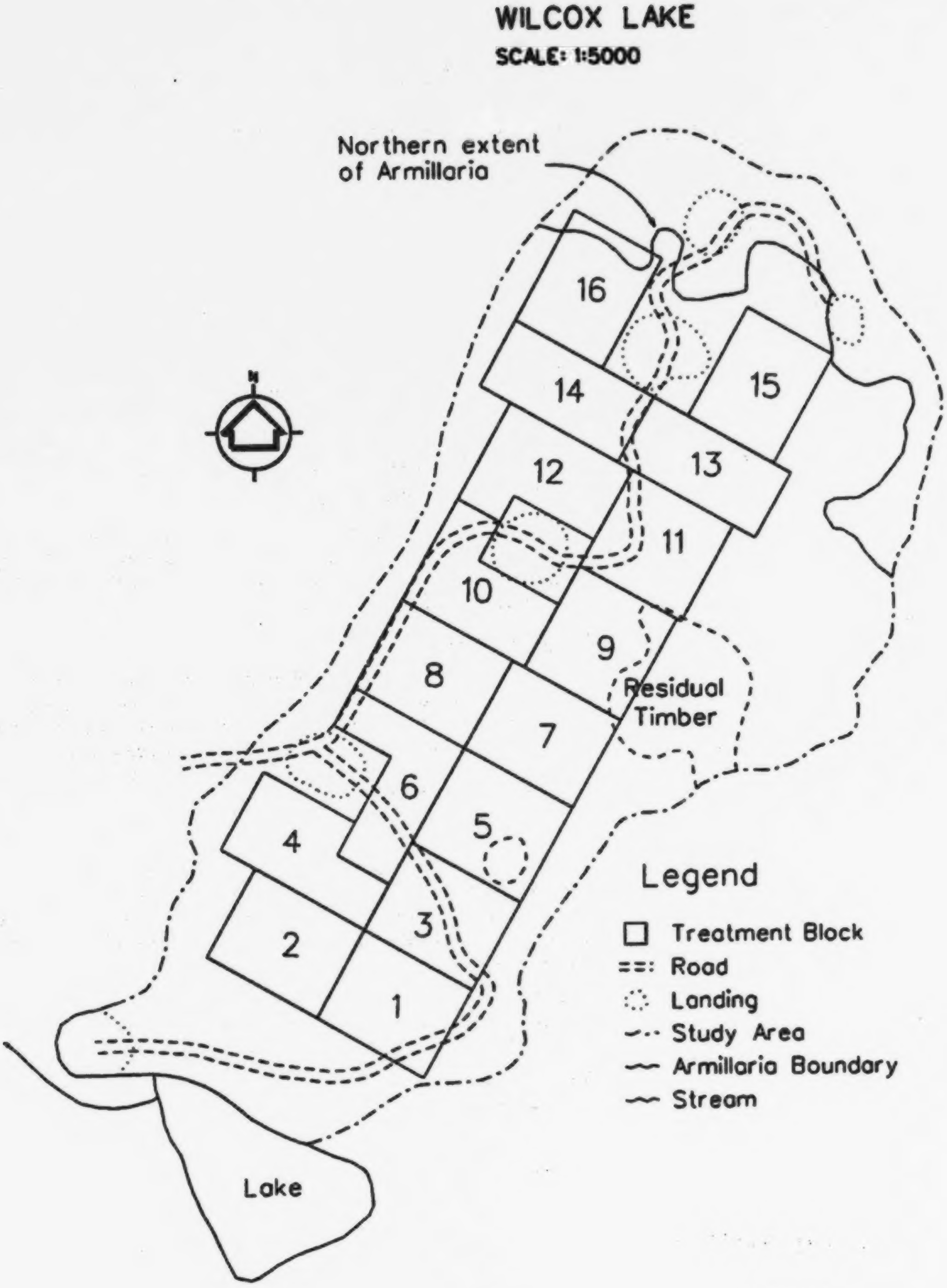
WILCOX LAKE
SCALE: 1:5000
Northern extent of Armillaria
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12
13
11
10
9
8
Residual Timber
7
6
5
4
3
2
1
Lake
Legend
☐ Treatment Block
==: Road
Landing
Study Area
Armillaria Boundary
Stream

SUMMARY 44

Project

Armillaria Sample Plots in Thinned and Unthinned Juvenile Stands

Author(s)

S. Zeglen

Study Objective

1. Quantify the spread rate of *Armillaria ostoyae* in juvenile Coastal Douglas-fir stands.

2. Investigate the impact of Armillaria on stand development and productivity, given treated and untreated stand conditions.

Overview

Layout and Treatments

See Table 44-a for site descriptions.

Sites were located in the Mid-Coast and Sunshine Coast Forest Districts. Plantation ages range between 13 and 18 years. Treatments were: thinning, thinning and pruning, and a control, at the Nusatsum and Scar Creek sites; and no treatment at the Coola Creek site.

Measurements

Ten 10-m radius circular plots are distributed throughout a treatment unit. Each unit is centered near, or contains, one or more Armillaria-infected trees. For all trees greater than 1.3-m high, the following data are collected: species, dbh, bearing and distance from plot center, and condition (i.e. dead, symptomatic, healthy), and causal agent, if any. Each tree is individually tagged for future reference.

Analyses

After 10 years, assessments of plot mortality will be conducted. This will consist of examining individual tree mortality and the relationship between dead and infected trees and their neighbours. The pattern of infection between adjacent trees will be analyzed to determine the spread characteristics of the pathogen.

Data on residual stems per hectare, dead and infected trees per hectare, and other stand factors will be analyzed to determine if productivity is significantly different between treated and untreated areas.

Data collection will continue, and a later analysis will be performed, if infection and mortality persist past the 10-year horizon.

Status

Ongoing.

History/Time Table

Treatment units will be re-assessed every two years until juvenile mortality due to Armillaria ceases.

Brief Summary of Results

None available at this time.

Working Plan/Reports/ Publications

None available at this time.

Maps

N/A.

Table 44-a. Site descriptions.

	Site		
	1/Nusatsum	2/Coola Creek	3/Scar Creek
Region	Vancouver	Vancouver	Vancouver
District	Mid-Coast	Sunshine Coast	Sunshine Coast
Opening No.	93D028-001	92N026-004	92N015-004
Plot Lat/ Long			
Opening Area (ha)	60	47	16
Stand History	L 1979 P 1980	L1975 P1976&1982	L1977 P1979&1986
Biogeoclimatic Subzone/ Site Series	CWHms2	CWHds1 / 01	CWHds1 / 03
Site Productivity	Good	Medium	Medium
Soil Texture	Sandy to Silty Loam	Silty Loam	Sandy Loam
Slope (%)	30	30	5
Aspect	West	Southeast	South
Elevation (m)	440	110	110
Current Stand Description	Hw56Cw26Ba15 Ss02At01	Fd90Cw6Pl4	Fd77Hw10Cw8 Dr3Ba2
Stand Age (y)	13	18	14
Stems/ha (no.)	6815	2916	3946
Disease Found	DRA	DRA / DRL	DRA
Stand Disease Incidence (%)		5 / 3	4
Plots Established	1995	1995	1995
Treatment Unit(s)	Control / Thinned	Control	Thinned
Prescribed Treatment(s)	/ Thin & prune	None	Thin & prune
Year of Treatments	/ 1993 & 1995		1996
Post-Treatment Density/ Stems/ha (no.)	6815 / 600-718	2916	810

No. of 10-m Radius Plots	10 / 10	10	10
Total no. sample Trees	333 / 175	307	319

See Appendix C for abbreviations.

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Appendix A. Lists of Research Priorities Presented and Discussed by Members of the Armillaria Research Working Group (ARWG)

The following are lists of priority research areas based on formal inquires of district and industry staff and researchers.

A-1. Duncan Morrison's 1991 Survey of Forest District and Industry Staff

>75 % of respondents ranked the following questions as a high or moderate priority:

1. How to manage partially cut stands?
2. Longevity of inoculum in stumps?
3. Does pre-commercial thinning affect root disease incidence?
4. Is disease incidence affected by planting spot?
5. Conifer/hardwood mixtures for root disease sites.
6. Resistance of larch to Armillaria species.
7. Alternative harvesting methods for root disease.
8. Productivity loss for a favourable cost/benefit.
9. Role of fire in spread and control.
10. G&Y curves for disease-free stands.
11. Relationships between insects and root diseases.
12. Control with a fallow period.

Other research-related questions raised by respondents:

1. Is root disease occurrence related to ecosystem association? What is the role of root disease in natural ecosystems?
2. What is the relative susceptibility of planted and natural stock?
3. What are the prospects for biological control of root diseases?
4. What is the ratio between visible and actual infection?
5. Is selective or small area stumping a viable treatment?
6. Various questions concerning growth and yield of stands in relation to amounts of disease (productivity loss), inventory database of diseased stands and effects on Timber Supply Area (TSA) yield analysis.
7. Productivity trials for pushover logging in various sizes and ages of timber.
8. Is there genetically based resistance to root disease?
9. What are the rates of disease spread in pure and mixed stands?

Duncan Morrison's list of research priorities identified from the above:

1. Partial cutting and alternative harvesting methods.
2. Effects of PCT on crop tree infection and mortality.
3. Species resistance to *Armillaria ostoyae* and species mixtures.
4. Inoculum dynamics in stumps.
5. Productivity of diseased stands and related topics.
6. Disease dynamics - rate of spread, visible/actual infections.
7. Fungal ecology.

A-2. Preliminary List of Research Needs, Raised at the October 4th, 1992 Meeting of the ARWG

1. Standardization of survey methods for different management objectives.
2. Quantification of the impacts of Armillaria species on productivity and on other resource values (e.g. wildlife). What is the lowest level of production if no action is taken to control Armillaria root disease - what is the "bottom equilibrium"?
3. What is the longevity of inoculum in stumps (by species)?
4. How well do the 3m or 2m planting rules work?
5. How effective are the treatment options (juvenile spacing, commercial thinning, harvesting/plantations)?
6. How does stand density versus treatment influence: Armillaria incidence and rate of spread, and crop volume response?

A-3. Further List of Research Needs, Raised at the April 21, 1993 Meeting of the ARWG

1. When should a plantation be considered for rehabilitation? (In some instances, free-growing assessments are undertaken before the root disease is fully expressed - this raises the question of legal obligation.) What are the rehab options?

2. What are the effects of planting densities on mortality?

3. What are the expected growth responses attributed to specific treatment options (e.g. rehabilitation). This information is needed for cost benefit analyses and adjustments to AAC contribution.

4. Data on growth, yield and mortality need to be tied together for a range of stand types and age classes (e.g. actual versus expected) - infected versus uninfected or predicted from growth and yield models. Suggested that Armillaria surveys be undertaken pre- and post-harvest to create a database which, over time, could be used to develop expected responses/treatment.

5. District/Regional Problem Analysis - to provide some measure of area currently identified with DRA and of area amenable to treatment. e.g. through review of history records for DRA, plantation, species, age class, site characteristics - with field verification (1%).

6. Effect of fire suppression on Armillaria root disease

7. Armillaria root disease and wildlife interactions.

8. Equipment use.

A-4. Response of Nelson Forest Region and District Staff to Questionnaire Regarding Armillaria-Related Research Priorities (1993)

1. What is the history behind the pixel survey? How accurate is it?

2. What are the roles of natural versus artificial regeneration on root rot sizes? Is there a difference in susceptibility between natural and planted regeneration.?

3. What is the long term prognosis (mortality, volume losses) for plantations with root rot? When should rehab be undertaken?

4. How is rotation length affected where root removal is not an option?

5. What are the treatment options regarding stand tending: spacing, brushing? What is the upper *Armillaria ostoyae* incidence prior to treatment?

6. What volume losses can be expected where stumping is not an option?

7. What are the equipment/harvesting costs associated with the various treatment options?

8. Should all under-storey be cut under seed trees or should the deciduous spp. be retained?

9. In cases where visual quality is a concern and push-over is an option, how small can a patch be before the benefits are lost?

10. What are the trade-offs between site degradation and stump removal particularly on fine textured or calcareous soils?

11. Cost/benefit analyses are required for each treatment option relative to the non-treatment option.

12. What are the nutrient losses/gains, soil impacts, successional links and nutrient requirements required post treatment?

13. The impact of root rot on growth and yield over a rotation needs to be quantified (by forest type, age, class, and management objective or tow) if economic/resource values(s) trade-offs are to be evaluated.

A-5. Overview of ARWG Priority Research Topic Areas (1994-98), Presented at the ARWG November 3, 1993 Meeting (not listed in any order of priority)

1. Basic Biology

– Resistance of western larch - mechanisms - (ongoing)

– Longevity of inoculum in stumps (by species)

– Planting Spots and the 2 and 3 m rules

– Visible/actual infections (ongoing for pre-commercial thinning in the IDF, ICH, and ESSF biogeoclimatic subzones)

(This information is needed to better design and understand the outcome of treatment options. These initiatives also directly address District questions.)

2. Operational Equipment/Harvesting Trials (with Time and Motion, and investigative data collection compiled annually in standard format).

(This information will address District's need for cost estimates, and will identify the limitation of the available equipment (e.g. costs, manoeuvrability, soil disturbance, injury to residual trees. This information is necessary to identify which equipment should be used in treatment trials (#2).)

3. Treatment Trials (control, conventional, pop-up, (and rehab for JS?) - to monitor incidence, rate of spread, crop volume response.

– juvenile spacing (control, conventional, Armillaria root disease treatment, rehab)

– harvesting/plantations (conventional/Armillaria root disease treatment)

– pre commercial thinning (control, conventional, Armillaria treatment)

(These long-term installations will provide comparative information on disease and crop response to conventional harvesting and alternative Armillaria *treatments. Over the long term this information can be used in cost/benefit analyses. The controls will provide information on the dynamics of* Armillaria *in the natural ecosystem.)*

4. Species Selection/Silvicultural Systems Option Trials for:

- conifer species
- deciduous species
- advanced regeneration
- deciduous/conifer mixes

5. Productivity Impacts (loss/gains) across the continuum: no treatment to intensive treatment

6. Cost Benefit Analysis of the Treatment Options

7. Validation of Prognosis Model

8. Treatment vs. No Treatment Impacts on Site Productivity/ Forest Health (e.g. site organic matter/nutrients, animal habitat, species diversity, insect/disease interactions)

9. Innovative Detection and Assessment Techniques (e.g. photogrammetry)

10. Standardization of Forest Health Survey Methods

11. Risk Rating Decision Aid (e.g. for basic and incremental activities and harvesting)

12. Site Sensitivity Analysis

Appendix B. Definitions [34]

Clones: a group of organisms originating via vegetative propagation from one individual.

Disease: any more or less prolonged disturbance of an organism that interferes with its normal structure or function. A disease may be caused by one or more agents. Causes of disease are both biotic and abiotic and include pathogenic micro-organisms, nutrient deficiencies or excesses, insects, and air pollutants. However, some pathologists exclude disturbances due to abiotic factors, referring to these as disorders.

Hazard: the degree to which the characteristics of the sampling entity (usually a tree or a stand) make it vulnerable to damage. It is equivalent to susceptibility.

Hypertrophy: abnormal over-development due to an increase in cell size.

Incidence: the proportion (0-1) or percentage (0-100) of diseased entities (normally a tree) within a sampling unit (normally a plot or a stand). To avoid confusion, the use of incidence should always be qualified with a description of the sampling entity and sampling unit. Where the proportion of damaging agent affected stands or polygons (sampling entity) is of interest in a higher level sampling unit, occurrence should be used. Some examples of incidence include: 1. the percentage of branches (sampling entity) affected on a tree (sampling unit); 2. the proportion of trees (sampling entity) affected in a plot (sampling unit); and 3) the percentage of plots (sampling entity) affected within a stand (sampling unit).

Intensity: the general characterization of the total amount of damage within a specific population or area. (i.e. Intensity = Damage = Incidence x Severity); Intensity (incidence and severity) is a characterization of disease in space, not in time. Because time is an unavoidable component of the I-S relationship it should describe the spatial pattern of disease at a particular (and identified) time. One must quantitatively determine both incidence and severity and know their relationship in order to calculate intensity.

Isolate: 1. To separate a micro-organism from its substrate and bring it into pure culture. 2. A single spore or a culture made by direct isolation from an infected host or other natural substrate and subcultures derived from it. 3. Term used to indicate collections of a pathogen made at different times.

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[34] Sources: Seem (1984), Doliner and Borden (1984), BCMOF (1994), De Long (1994).

Occurrence: the proportion of affected stands or polygons within a higher level sampling unit (e.g. inventory or growth type groups, or BEC zones, subzones, or variants). Occurrence may be expressed as a proportion or percent. Where the proportion or percent of damaging agent affected trees (sampling entity) in the sampling unit is of interest, incidence should be used. Some examples include: 1. a stand (sampling entity) has the damaging agent in the inventory type group (sampling unit); 2. 80% of pure spruce stands (sampling entities) have a damaging agent in an inventory type group (sampling unit).

Pathogen: any agent, whether a living organism or abiotic agent, that induces disease.

Pathogenicity: the capacity to cause disease. May be qualified—e.g. as high, moderate, or low—but the term virulence is preferable for indicating the degree to which a pathogen is able to induce disease. Pathogenicity may be used to describe a group of organisms, such as a genus, or species, while virulence is used to describe the ability of a particular isolate, strain or other subgroup to cause disease under particular conditions. It is thus possible to refer to a nonvirulent strain of a pathogenic organism.

Population: a collection of sampling entities about which we wish to make an inference. Some examples of a population include: trees in a plantation, plots in a stand, or stands in a biogeoclimatic ecosystem classification unit (BEC) subzone.

Risk: the probability and expected severity of sampling entity to damage. Risk is a function of numerous components including sampling entity hazard, sampling unit conditions, proximity to damaging agents and the incidence of those agents.

Sampling entity: an object on which a measurement is taken (normally a tree or a stand).

Sampling unit: a non-overlapping collection of sampling entities from a population. Some examples of a sampling unit include: a plot, a stand, a polygon, an inventory type group, or a BEC subzone.

Severity: the quantity of disease affecting entities within a sampling unit (e.g. averaged lesion counts per root system when the sampling unit is a group of roots).

Species: A group of actually (or potentially) interbreeding natural populations that are reproductively isolated from other such groups. The members of a species form (1) a reproductive community, in which individuals recognize each other as potential mates, (2) an ecological unit, which interacts as a unit with other species with which it shares the environment, and (3) a genetic unit consisting of a large, interconnected gene pool.

Time and Motion Study: can be used to monitor productivity of operations for objectives including:

- time standards (targets) for planning, costing, and scheduling; and
- productivity evaluation.

In productivity evaluation of timber harvesting operations, shift level and detailed level methods are commonly used.

Shift Level: shift level studies provide an overview of average hourly production, based on observer or worker records of hours worked and pieces handled during an entire operation. Shift level studies monitor machine usage or productive machine hours (PMH). PMH is the in-shift time that the machine is doing what it is scheduled to do, such as skidding or pushover falling. Non-mechanical and mechanical delays are taken out of total time. A Servis recorder is commonly mounted on a machine to measure when the machine is working or 'in motion'.

Detailed Level: the detailed level study determines and monitors each activity a machine or person does during the hours worked. Work performed by a machine or person is divided into activities or elements. An element is a distinct part of an activity (i.e. hooking as part of skidding). It can be made up of one or more motions and/or machine activities selected for convenience of observation and timing. The two most common approaches for monitoring timber harvesting activities are stop watch studies and work sampling:

1. Stop watch: involves continuous timing to observe, measure, and record the length of time required to perform an activity. Notations of distance travelled, pieces handled, and piece size are also documented.
2. Work sampling: consists of random or fixed interval observations to determine how much of the total work time has been spent in various states of activity or inactivity. Distance travelled, number of pieces, and piece size are collected with independent tallies.

Virulent: capable of causing a severe disease.

Virulence: degree of pathogenicity; especially of a particular isolate, pathotype or strain.

Appendix C. Abbreviations Used in Site Description Tables

Codes and abbreviations	Definitions
A	animal
DM	dwarf mistletoe
DS	stem rust (on lodgepole pine)
DML	larch dwarf mistletoe
DMP	lodgepole pine dwarf mistletoe
DRA	Armillaria root disease
DRT	Tomentosus root rot
DRL	laminated root rot
DSG	western gall rust
IBM	mountain pine beetle
IBD	Douglas-fir beetle
OS	overstory
PL	plot

(brackets = minor occurrence)